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EMISSION IMPACT OF CURRENT AND POSSIBLE FUTURE CANADIAN FUELS ON HEAVY DUTY DIESEL ENGINES

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On a soumis à des essais d'émissions en régime transitoire deux moteurs diesel lourds (DDC, série 60 et Cummins NTCC 400) en utilisant six différents carburants diesel.

Les essais avaient comme objectifs :

de déterminer le taux et la nature des émissions produites relativement aux normes d'émissions des véhicules lourds de l'U.S.E.P.A. 1991 et 1994, que le Canada envisage d'adopter;

de déterminer l'effet des caractéristiques du carburant utilisé (teneur en soufre, teneur en substances aromatiques et point de distillation à 90%) sur les émissions gazeuses et les particules produites par les moteurs diesel;

d'établir une corrélation entre les résultats d'essai obtenues et ceux du programme VE-1 des États-Unis de façon que l'étude touche à un plus grand éventail de caractéristiques de carburant et à leurs effets sur les émissions gazeuses et les particules produites par les moteurs diesel.

On a utilisé un moteur DDC doté d'une commande électronique Detroit Diesel (DDEC) et donc à la fine pointe de la technologie des moteurs diesel. Ce moteur a été conçu pour produire un faible taux d'émissions, probablement conforme au taux établi dans la norme américaine d'émissions 1991 (5 g/bhp-h NO_x et .25 g/bhp-h de particules). Le moteur Cummins NTCC 400 utilisé était un modèle moins récent, à commande mécanique variable de l'avance à injection, conforme aux normes d'émissions de 1988 de la Californie (6 g/bhp-h NO_x et .6 g/bhp-h de particules).

Les six carburants diesel (A-F) utilisés pour l'essai représentent divers carburants canadiens qui sont utilisés à l'heure actuelle ou qui pourraient être utilisés à l'avenir.

Carburant	Source
A	Réf. de CRC/SwRI
B	Mélange conventionnel-30% synthétique
C	100% synthétique
D	Conventionnel
E	Conventionnel
F	Conventionnel (Réf. ORTECH)

Les six carburants ont été analysés. Voici leurs caractéristiques :

TABLEAU 6.1.1

Rapport d'analyse des carburants

Carburant	Tenure en soufre (% au poids)*	Point de distillation à 90% (°C)**	Teneur en substances aromatiques (% au volume)***
A	.15	317	28.4
B	.20	329	36.6
C	.01	336	22.3
D	.52	349	34.7
E	.40	358	30.1
F	.19	283	25.5

* (D4294)
** (D86)
*** (FIA D1319)

Afin de pouvoir définir les facteurs de corrélation entre les deux groupes d'essais, nous avons demandé aux entreprises Cummins et DDC de nous procurer les résultats préliminaires des essais d'émissions VE-1. Mais, comme il n'a pas été possible d'obtenir un ensemble de données complet et officiel à temps pour le présent projet, il a été décidé que l'analyse des tendances serait fondée uniquement sur les résultats du projet. Cette analyse allait permettre de déterminer s'il existe ou non une relation linéaire entre les émissions produites et les caractéristiques des carburants utilisés.

Les émissions de particules varient entre .19 et .33 (+.14 g/bhp-h) pour le moteur DDEC et entre .46 et .61 (+.15 g/bhp-h) pour le moteur NTCC 400. Les résultats des essais indiquent qu'il est possible, grâce à la technologie des moteurs, de réduire considérablement les émissions de particules. Ainsi, selon le carburant utilisé, le moteur DDEC a produit environ 50% moins de particules que le moteur NTCC 400.

Le taux d'émission de particules de .19 du moteur DDEC satisfait à la norme de 1991 fixée à .25 g/bhp-h. Par

contre, lorsque les émissions atteignent un taux de .33 g/bhp-h, elles dépassent les limites permises. Il en est de même pour le moteur NTCC 400; lorsque le taux des émissions se situe à .46 g/bhp-h, il satisfait à la norme de 1988 fixée à .60, mais lorsqu'il atteint .61 g/bhp-h, la norme est dépassée. Il est donc évident que les caractéristiques du carburant sont des paramètres qui peuvent faire qu'un moteur satisfasse ou non aux normes d'émissions.

Le taux d'émissions d'hydrocarbures total produites par le moteur DDEC varie entre .15 et .65 (+.50) et entre .41 et .49 (+.08) g/bhp-h, pour le moteur NTCC 400. On peut donc conclure que le moteur NTCC 400. On peut donc conclure que le moteur DDEC est plus sensible aux caractéristiques du carburant que le moteur NTCC 400. Le taux d'émissions d'hydrocarbures total des deux moteurs, quel que soit le carburant utilisé, se situe bien en-dessous de la norme de 1.3 g/bhp-h.

Le taux d'émissions de NO_x du moteur DDEC varie entre 4.34 et 4.77 (+.43) et celui du moteur NTCC 400 varie entre 4.12 et 4.58 (+.46) g/bhp-h. Bien que les deux moteurs produisent des taux d'émissions de NO_x semblables, le moteur DDEC a produit un taux de particules inférieur tout en présentant un taux d'émissions de NO_x inférieur à 5.0 g/bhp-h. De plus, les deux moteurs sont à peu près aussi sensibles l'un que l'autre aux variations des caractéristiques des carburants.

Les émissions de CO du moteur DDEC varie entre 2.1 et 2.66 (+.56) et entre 2.16 et 2.75 (+.59 g/bhp-h) dans le cas du moteur NTCC 400. Les deux moteurs ont produit sensiblement le même taux d'émissions de CO et ont réagi à peu près de la même façon aux changements des caractéristiques des carburants. L'augmentation de .59 semble considérable, mais le taux le plus élevé obtenu (2.75) demeure bien inférieur à la norme de 15.5 g/bhp-h.

Le taux d'émissions de soufre (déterminé à l'aide de filtres de prélèvement des particules) du moteur DDEC varie entre .04 et .22 (+.18) et celui de moteur NTCC 400, entre .05 et .13 (+.08 g/bhp-h).

À la lumière des données d'émissions recueillies, on ne peut établir aucune relation linéaire entre les émissions produites et les caractéristiques du carburant utilisé. En général, le taux d'émissions augmente à mesure que les trois valeurs caractéristiques du carburant augmentent. Aucune valeur caractéristique des carburants n'a produit une augmentation très marquée des émissions. Le carburant D à haute teneur en soufre (.52%), à point de distillation à 90% de 349°C et à haute teneur en substances aromatiques (34.7%), a produit le plus haut taux d'émissions.

Les carburants B et C n'ont pas produit un taux d'émissions ni des caractéristiques d'émissions anormales comparativement aux autres carburants, ce qui semble indiquer que le carburant diesel dérivé des sables bitumineux donne un rendement comparable au carburant diesel ordinaire.

Les dispositifs de traitement des gaz d'échappement offrent la possibilité de ramener le taux des particules émises à .10 g/bhp-h en présence des carburants diesel actuels ou éventuels. Il est donc nécessaire d'étudier les effets des caractéristiques du carburant diesel utilisé dans un moteur à la fine pointe de la technologie et avec des dispositifs de traitement des gaz d'échappement.

EXECUTIVE SUMMARY

Two heavy-duty diesel engines (DDC series 60 and Cummins NTCC 400) were transient emission tested using 6 different diesel fuels.

The objectives of the project are as follows:

- Determine and characterize the emissions with respect to the U.S. E.P.A. 1991 and 1994 heavy-duty emission standards being considered for Canadian legislation.
- Characterize the impact of fuel properties (% S, % aromatics and 90% PT, on diesel engine gaseous and particulate emissions.
- Correlate the results with those of the U.S. VE-1 program to cover a wider range of fuel properties and their impact on diesel engine gaseous and particulate emissions.

The DDC engine was equipped with Detroit Diesel Electronic Control (DDEC) and represented the newest diesel engine technology. The engine was designed to be a low emissions engine possibly meeting the 1991 U.S. emission standard (5 gr/bhp-hr NO_x and .25 gr/bhp-hr particulate). The Cummins NTCC 400 was an older design engine which uses mechanical variable timing (MVT) to meet 1988 California emission standards (6 gr/bhp-hr NO_x and .6 gr/bhp-hr particulate).

The six diesel fuels (A - F) used in the project represent a range of current and possible future Canadian fuel.

Fuel	Source
A	CRC/SwRI Ref.
B	30% Syn/Conv Mix
C	100% Synthetic
D	Conv
E	Conv
F	Conv(ORTECH Ref.)

All six fuels were analyzed and showed the following properties:

TABLE 6.1.1

FUEL ANALYSIS SUMMARY

FUEL	%S (WT%)*	90 %Pt (^{O}C)**	AROMATICS (% VOL)***
A	.15	317	28.4
B	.20	329	36.6
C	.01	336	22.3
D	.52	349	34.7
E	.40	358	30.1
F	.19	283	25.5

* (D4294)
** (D86)
*** (FIA D1319)

Preliminary VE-1 emission results were obtained through Cummins and DDC in order to establish correlation factors with the VE-1 program. A complete and official emission data set was not available in time to be used for this project. It was decided to conduct a trend analysis using data from this program alone. The trend analysis will show if there is any non-linear relationship between emissions and fuel properties.

The particulate emission for the DDEC ranges from .19 to .33 (+.14 gr/bhp-hr) and ranges from .46 to .61 (+.15 gr/bhp-hr) for the NTCC 400. The emission test results indicated that major particulate emission reduction can be achieved by engine technology. Depending on the fuel test, the DDEC engine produced approximately 50% less particulate than the NTCC 400.

For the DDEC engine, particulate emission at .19 level will meet the 1991 standard of .25 gr.bhp-hr. At .33 gr/bhp-hr level, it exceeds the standard. The same holds true for the NTCC 400, at .46 gr/bhp-hr, it meet the 1988 standard of .60. At .61 gr/bhp-hr, it exceeds the standard. This clearly indicated that the fuel property is one of the emission parameters that can result in an engine to either meet or exceed the standards.

The THC emission for the DDEC ranges from .15 to .65 (+.50) and ranges from .41 to .49 (+.08 gr/bhp-hr) for the NTCC 400. This indicated that the DDEC is more sensitive to fuel properties as compared to the NTCC 400. The THC level for both engines for all test fuels is well below the standard of 1.3 gr/bhp-hr.

The NO_X emissions for the DDEC range from 4.34 to 4.77 (+.43) and range from 4.12 to 4.58 (+.46 gr/bhp-hr) for the NTCC 400. Both engines have similar NO_X emission levels but the DDEC engine was able to achieve lower particulate emission levels while maintaining NO_X emissions at below the 5.0 gr/bhp-hr level. Also, both engines have about the same sensitivity towards fuel property changes.

The CO emissions for the DDEC ranges from 2.1 to 2.66 (+.56) and ranges from 2.16 to 2.75 (+.59) gr/bhp-hr for the NTCC 400. Both engines show almost identical CO emissions output and have about the same sensitivity toward fuel property changes. The .59 increase seems to be high but the higher CO level (2.75) is still well below the standard of l5.5 gr/bhp-hr.

The sulphate emission (as determined using particulate sampling pads) for the DDEC ranges from .04 to .22 (+.18) and ranges from .05 to .13 (+.08) gr/bhp-hr for the NTCC 400.

Emission data did not indicate any non-linear relationship between emission and fuel properties. In general, emissions increase as the three fuel properties increase. There was no fuel property value at which emission increased dramatically. Fuel D has high %S (.52%), 90% Pt. (349C) and Aromatic (34.7%) gives the highest emission values.

Fuel B and C did not show abnormal emission characteristics as compared to other fuels. This seems to indicate that tar sand derived diesel fuel operates comparably to conventional diesel fuel.

The exhaust after treatment technology has the potential to reduce the particulate level to .10 gr/bhp-hr with current and possible future diesel fuel properties. Therefore, there is a need to study the emission impact of diesel fuel properties in combination with state-of-the-art engine and exhaust after treatment technology.

1. INTRODUCTION

At the present time, heavy-duty diesel engine emissions standards in Canada are equivalent to U.S. standards. Canada indicated the intent to adopt new emission standards starting 1988. On June 11, 1986, Canada adopted more stringent Heavy Duty Standards, effective December 1, 1988. These represent a change in engine testing procedure from steady state conditions to transient conditions, and reduction of allowable emission levels for total hydrocarbons, carbon monoxide, nitrogen oxides and total particulates. The Canadian Standards are equivalent to the U.S. 1990 Standards as shown in Table 1.1.

In the U.S., gradual reductions in allowable particulate emissions levels have been adopted in 1988, 1991 and 1994 as shown in Table 1.1. The reduction in particulate from a .6 gr/bhp-hr level (1988) to a .1 gr/bhp-hr level for urban buses (1991) and truck (1994) requires technology still under development.

Canada has announced intent to review new standards for 1991 and 1994, but has not yet specified the levels of such standards. The Canadian Government is therefore currently evaluating the social and economic impact of tighter emissions standards for heavy-duty diesel engines, but at the present time, a number of uncertainties exist, such as:

(i) the cost of engine and other emission control technologies to meet the tighter standards:

(ii) the possible fuel economy penalty associated with the tighter standards:

(iii) the impact of Canadian diesel fuel quality and ambient conditions on the ability of the engine technologies to meet the emission standard proposed:

(iv) the need and cost of any changes in Canadian diesel fuel quality to meet these regulations and operate successfully with any new engine and other emission control technology.

The above uncertainties are of concern not only to engine manufacturers, who have the commercial responsibility for ensuring compliance with the emission standards, but also to the Canadian petroleum industry. Following early discussion with the Canadian Oil Industry, Energy, Mines and Resources

Canada (EMR) became concerned about the possible emission impacts of current and possible future Canadian diesel fuel composition on Canadian emission standards in 1991 and 1994. This concern related to the possible requirement for more highly refined Canadian diesel fuel to meet new standards, and the cost impact to the petroleum industry. Currently, the U.S. E.P.A. is considering legislating the use of diesel fuel in the U.S.A. which should contain only low (less than 0.05% by mass) levels of sulphur and possibly control to a lower aromatic level and/or higher cetane index.

Some petroleum industry members agree with EMR that there is a need for a research program to resolve some of the above uncertainties. The original intent was for EMR and the petroleum industry to fund, on a 50/50 basis, a research program to investigate the impact of Canadian diesel fuel composition and other operation parameters on diesel engine gaseous and particulate emissions using possible 1994 test fuels supplied by the petroleum industry. Upon investigation and discussion to develop such a program, it was recognized that participation in both funding and technical support are needed from the whole petroleum industry, other government agencies and U.S. engine manufacturers.

It was also recognized that a non-profit, independent research organization could facilitate coordination and development of such a program. ORTECH International fitted this role due to its capability and experience in emission research programs of heavy-duty diesel engines. The Advanced Engine Technology Group (AET) at ORTECH has extensive experience in the many disciplines required in the area of heavy duty diesel emission research projects. AET has been working in the field of developing diesel emission control technology for the past eleven years, and during that time, has taken a world lead in experience in conducting diesel emission research.

For the above reasons, ORTECH was contacted to carry out the coordination and development of the program. ORTECH therefore proposed a four-phased program with objectives outlined as follows:

Phase I) Project definition and work statement for Phases II, III and IV.

Phase II) Engine testing and emission characterization.

Phase III) Cold start, and evaluation of trap oxidizer and oxidation converter technology on emission control performance.

Phase IV) Prototype trap technology evaluation.

Phase I was proposed to EMR and a number of petroleum companies. The proposal was accepted and funded jointly by EMR and four petroleum companies (Shell, Petro-Canada, Texaco and Esso). The work was carried out through the following stages:

- Meetings with representatives from the petroleum industry, Esso, Texaco, Shell and Petro-Canada were held to select a fuel matrix and engine test program for study in the following phases of the work.
- Meetings with representatives from engine manufacturers, Caterpillar, Cummins and DDC were held to select and secure supply of appropriate engines for the test program.
- A meeting was held in Ottawa with representatives from Energy, Mines and Resources, Environment Canada, Transport Canada, and the National Research Council to solicit their input regarding the work statement for Phases II-IV.
- A draft report for Phase I was prepared and a final meeting was held with representatives from the petroleum industry, government agencies and U.S. engine manufacturers.

During the course of defining the research program objectives, it was recognized that the concerns mentioned above have already prompted action in the U.S. A similar program is being sponsored in the U.S. by the Co-ordinating Research Council (CRC) which is an organization funded jointly by the American Petroleum Industry (API) and U.S. Engine Manufacturers Association (EMA). This program, which is code-named VE-1, will likely cover much of the range of fuel compositions of Canadian diesel fuels. The research program is being conducted by Southwest Research Institute (SwRI).

The VE-1 proposal was reviewed by EMR, Esso and ORTECH. Further communications with CRC representatives indicated the program is behind the original schedule and changes are being made to the program. ORTECH, EMR and Esso personnel visited CRC and Southwest Research Institute to obtain full details of the CRC program.

The VE-1 program used the following engines:

- Cummins NTCC-400 (Mechanical Variable Timing)
- DDC Series 60 11.1 Litre-315 HP (DDEC)
- Navistar 7.3 Litre - 180 HP (ID Injection).

A total of seven fuels were tested with each engine. The seven fuel matrix is shown in Figure 6.1.1 with additional fuels to be added to the matrix developed to show the impact of aromatics, sulphur and 90% distillation point.

The meeting with SwRI showed that there was soon to be a non-linear relationship between increasing aromatic content and particulate emissions. Since some Canadian diesel fuels could have different compositions due to crude source and refining differences from those in the U.S.A., it was concluded that it would be necessary to mount a Canadian test program, and intercalate it with the CRC program results. This view was subsequently supported by other petroleum industry members during a review of the CRC fuel matrix. It was evident that in addition to differences in composition, Canadian specifications could have higher sulphur and end points than those covered in the CRC fuel matrix. Petroleum industry members therefore agreed to develop a Canadian fuel matrix lying outside the CRC matrix, in order to better understand the possible impact of such fuels on particulate emission characteristics. It was also agreed that there should be some overlap with the CRC matrix in order to provide lab to lab correlation, and improve the confidence level for intercating the CRC and Canadian results. Since it was necessary to generate a fuel test matrix with the petroleum industry, and select test engines, three sub-committees were formed representing:

- petroleum industry
- engine manufacturers
- government.

Table 1.2 lists the committee members.

The funding for Phase II was provided jointly by EMR which represents the government commitment and PACE (Petroleum Association for the Conservation of the Canadian Environment) which represents the petroleum industry. Engine manufacturers (Cummins and DDC) would provide the test engines and technical assistance to the project. Funding for Phases III and IV will be decided upon completion of this project.

The petroleum sub-committee selected the five test fuels. These encompass the Canadian concerns of end point and aromatic properties outside the VE-1 fuel matrix, but relevant to possible future Canadian diesel fuels. The engine sub-committee selected two test engines which have emission characteristics of future U.S. (1990) new diesel engines to be used in Canada. The engines selected were a DDC Series 60 engine with Detroit Diesel electronic control (DDEC) (300 HP at 1800 rpm) and a Cummins NTCC-400 engine with mechanical variable timing (MVT) (400 hp at 2100 rpm). The initially selected test fuels and properties are shown in Table 1.3.

2. OBJECTIVES

The primary program objectives are summarized as follows:

(1) Determine and characterize the emissions with respect to the U.S. EPA 1991 and 1994 heavy duty emission standards being considered for Canadian legislation.

(2) Characterize the impact of fuel properties on diesel engine gaseous and particulate emissions, including the effect of synthetic crude derived products and higher 90% distillation point.

(3) Correlate the results with those of the U.S. VE-1 program to cover a wider range of fuel properties and their impact on diesel engine gaseous and particulate emissions.

The combined results of the U.S. and Canadian evaluations should cover the full range of fuel characteristics in North America and in particular, will provide U.S. engine manufacturers with Canadian needs and give Canadian refiners an insight of fuel composition changes that may be required to meet the proposed 1991 and 1994 emission regulations.

3. MAJOR TASKS

The original 15 project tasks as defined in the proposal, were redefined and simplified once the project was begun, to facilitate smoother project management and reporting. Three major tasks were defined:

Task 1 Test engine and fuel procurement and project management.

Task 2 Testing of the first engine (Cummins NTCC 400 MVT).

Task 3 Testing of the second engine (DDC 6R-544 with DDEC I).

The two engines tested were the identical ones to the SwRI program.

4. PROGRESS OF WORK

Details of the ORTECH heavy duty diesel emission test facility and the transient emission test procedures used in the program can be found in Appendices A and B respectively.

4.1 Task 1 - Engine, Fuel Procurement and Project Management

4.1.1 Engine Procurement

Discussions were held with Cummins in January of 1988, for the delivery of a Cummins NTCC 400 engine. The particular engine being discussed had previously been baselined at SwRI and Cummins, so would provide baseline and correlation data. The Cummins NTCC 400 engine in question was received by ORTECH early in February, 1988.

The DDC engine originally scheduled for the program was a DDC Series 60 engine available at ORTECH. However, in a December 1987 Petroleum Committee meeting, it was recommended that the engine being tested at SwRI should be used. This DDC Series 60 engine had been modified to exhibit emission characteristics close to the 1991 Standards and hence, would be more appropriate for this project.

ORTECH staff contacted CRC, SwRI and DDC in January of 1988, to make arrangements to obtain the engine when the SwRI program was completed. However, it was found that the SwRI engine might not be available until at least August of 1988. Further enquiries in February clarified that the engine testing at SwRI would continue until April 1988, but was then scheduled for testing at the Environmental Protection Agency (EPA) in the U.S. DDC approached EPA with respect to testing the engine at ORTECH first and made the necessary arrangements in April of 1988. The test engine was shipped to DDC and subsequently was received at ORTECH, May 18, 1988.

Both engines were performance tested upon arrival, with the following results:

Cummins NTCC 400

Engine Type:	14 litre In-line 6 cyl., 4-stroke turbocharged DI engine with mechanical variable timing.
Observed Max. Output:	345 Bhp @ 2100 rpm 302 Bhp @ 1300 rpm (Peak Torque Speed)
Idle:	675 rpm
Max. No-load speed:	2300 rpm

DDC Series 60

Engine Type:	11.1 litre In-Line 6 cyl., 4-stroke turbocharged DI engine with electronic injection control (DDEC-I)
Engine Serial No.	6R-544 (Series 60)
Observed Max. Output:	315 BHP @ 1800 RPM 274 BHP @ 1200 RPM (Peak torque speed)
Observed Idle:	500 rpm
Max. no-load speed:	1840 rpm (High-idle)

The performance data were approved by engine manufacturers on engines deemed to be in good shape for emission testing. All performance data details are included in Appendix C.

The lubrication oil used for both test engines was that used in the SwRI program and was shipped directly from SwRI. The use of identical lubrication oil provided one less variable in correlating with SwRI results.

4.1.2 Fuel Procurement/Analysis

Details for the fuel procurement were worked out late in 1987, with respect to fuel characteristics and suppliers. The suppliers and receipt of the fuels are summarized below:

Fuel	Source	Receipt
A	CRC/SwRI Ref.	May, 1988
B	30% Syn/Conv Mix	Feb. 1988
C	100% Synthetic	May, 1988
D	Conv	June, 1988
E	Conv	May, 1988
F	Conv(ORTECH Ref.)	March, 1988

The reference CGSB Type B truck fuel (F) was obtained in bulk (1400 gallons) by ORTECH through normal commercial distributors. Two 45 gallon drums of Fuel A were received from SwRI. ORTECH received 8 x 45 gallon drums of each of Fuels B, C, D and E.

With the receipt of the final batch of fuel in June, 1988, samples were delivered to Petro-Canada in Mississauga for distribution to the participants in the fuel analysis. A round robin fuel analysis of all fuels had been established at the December, 1987, Petroleum Committee Meeting. The participants were NRC, Esso, Texaco, Petro- Canada and Shell.

4.2 Task A - Testing of the Cummins NTCC 400 MVT Engine

Arrangements were made in January, 1988, with Cummins for the delivery of the NTCC 400 engine. Preparations were begun in January for the installation of the engine in the ORTECH Test Cell #8.

The engine was received in early February, set up and instrumented. Baseline data and torque curve were also received and a communication link established between ORTECH and Cummins' technical staff.

Steady state performance tests were performed (2-pt. check) at torque-peak (1300 rpm) and peak power (2100 rpm) conditions. Results are shown in Table C.4.2.1. All parameters compared favourably with Cummins' data. All preliminary and set up work was done using the ORTECH Reference Fuel F. A preliminary manual torque curve was generated. However, engine/dynamometer coupling problems were encountered. A potential problem was also encountered with fuel return pressure sensitivity affecting engine power. Coupling repairs were made and a fuel system recirculating tank ordered to duplicate the fuel system set-up at Cummins.

Due to delays in receiving the recirculating tank, an in-house system was used to generate another manual torque curve (see Figure C.4.2.1). However, fuel cooling problems indicated that the recirculating tank in conjunction with a fuel cooler, was necessary before testing could be continued.

Generation of computer control coefficients was begun in March, 1988, and results analyzed in April. These coefficients form the basis for later transient cycle optimization.

The recirculating tank fuel system was installed in May. A manual torque curve was generated as shown in Table C.4.2.2, Figure C.4.2.2 and C.4.2.3. The engine was operated from low idle to high idle and fuel was drawn directly from a fuel drum. As shown in Figure C.4.2.2, the ORTECH torque curve is comparable to that of Cummins and matches SwRI up to 1200 rpm. Performance data (Table C.4.2.3) was also recorded. All data was sent to Cummins for approval.

Once engine performance was verified, a modified EPA transient cycle was generated as shown in Figures C.4.2.4 to C.4.2.7 and input into the control computer. The modified cycle differs from the standard EPA cycle in that the motoring torques are replaced by idle torques.

The cycle is composed of four different segments, namely New York Non-Freeway (NYNF), Los Angeles Non-Freeway (LANF), Los Angeles Freeway (LAF) and a repeat of NYNF. Each segment is approximately 300 seconds in length for a total cycle time of 1200 seconds. The cycle as given by EPA is in normalized (%) format. From the normalized cycle, various cycles can be generated according to each engine's torque curve.

Cycle optimization was conducted during July and August, 1988. Results during July were poor, with none of the EPA regression parameters passed. Hardware changes were made for faster engine control response. Optimization during August proved more successful, but some regression parameters were still not passing. The status of optimization to the end of August is illustrated in Table C.4.2.4.

By mid-September, careful analysis of the data indicated that in order to get faster response, the dynamometer would have to be rebuilt.

The dynamometer was dismantled and all internal components were descaled and painted. New trunnion and rotor bearings were installed and the dyno was reassembled and tested. It appeared that high dyno idle load was the problem. The dyno is now capable of maintaining 24 ft-lb. (idle loading) for all engine speeds.

Engine performance data was also verified as shown in Table C.4.2.5. The data shows better correlation with Cummins' data previously obtained (Table C.4.2.6).

Cycle optimization continued and Table C.4.2.7 shows the coefficients used. The best cycle regression results are shown in Table C.4.2.8. Two out of the thirteen parameters failed the regression requirement. It was felt that the engine is following the cycle sufficiently well to produce repeatable emission results.

Official emission testing over the modified EPA transient cycle was performed following the schedule below:

Date	Fuel
October 21, 1988	F
October 28, 1988	F
November 4, 1988	C
November 10, 1988	A
November 17, 1988	B
November 24, 1988	D
December 1, 1988	F
December 8, 1988	E

For each fuel, a new torque curve was generated along with a 2 pt. performance check. From the torque curves, a fuel specific modified EPA transient cycle was generated and input into the control computer. The cycle regression analysis was checked before the emission test was performed.

Figures C.4.2.11 through C.4.2.13 show a typical reference cycle with reference engine cycle and actual cycle data.

Analysis of particulate filters and calculation of gaseous and particulate emissions were ongoing during the testing period. Particulate sulphate analyses were performed in February, 1989. Statistical analysis of emission results were carried out.

The Cummins NTCC 400 test engine was pulled from the cell and shipped back to Cummins early in 1989.

4.3 Testing of DDC Series 60 Engine

The proposed test engine at ORTECH was replaced, on the recommendation of the Petroleum Committee, by the DDC Series 60 engine being tested at SwRI. Testing at EPA, Ann Arbor, was rescheduled by DDC so that ORTECH could test the engine first. SwRI completed the test program in April and shipped the engine to DDC. A Consignment Agreement was signed between ORTECH and DDC for the use of the engine.

ORTECH received the engine from DDC on May 18th, 1988. A communication link was established between Mr. Bill Baker of DDC and ORTECH technical staff. Engine set-up, performance data and transient data were received from Mr. Baker for both the DDC and SwRI tests. Emission data was received for the DDC baseline testing and SwRI testing on CRC-5 and CRC-7 fuels.

The engine was installed and instrumented in Test Cell #7. The engine oil was changed using the identical oil used in the SwRI program. Preliminary performance checks were made at peak torque and peak horsepower, along with a manual torque curve.

Repairs were completed on the dynamometer and fuel sensor during the first week of June, 1988. The steady state performance points were then checked. As shown in Table C.4.3.1, all parameters compared well with the DDC data.

A manual torque curve was also repeated. The results were compared to DDC data in Figure C.4.3.1 and Table C.4.3.2. The comparison is within 2%, except at points below 900 rpm. SwRI data is compared in Figure C.4.3.1 and Table C.4.3.3 for the CRC Fuel 7. SwRI data is generally about 5% higher than the ORTECH data.

The modified EPA heavy-duty transient cycle was then generated using the manual torque curve and entered into the control computer. Initial computer control coefficients were then generated. These coefficients form the basis for transient cycle optimization.

Transient cycle optimization started at the end of June.

Preliminary regression analyses are shown in Table C.4.3.4. Cycle optimization was completed on the DDC engine by mid-August, 1988. The final regression analysis which passed all the EPA statistical parameters is shown in Table C.4.3.5. The actual cycle compared to the reference cycle is illustrated in Figures C.4.3.2 - C.4.3.4.

Preliminary baseline emissions were performed on the Reference Fuel F at the end of August.

During September, 1988, two preliminary emission tests were performed using Fuel C, to evaluate test to test variation. An official emissions test on Fuel F was performed at the end of September.

Official emission testing over the modified EPA transient cycle was performed, following the schedule below:

Date	Fuel
September 20, 1988	F
October 15, 1988	A
November 8, 1988	B
November 15, 1988	C
November 22, 1988	D
November 29, 1988	F
December 6, 1988	E

For each fuel, a new torque curve was generated, along with a 2-pt. performance check. From the torque curves, a fuel specific modified EPA transient cycle was generated and input into the control computer. The cycle regression analysis was checked before the emission test was performed.

Table C.4.3.6 summarizes the performance checks for the various fuels.

Analyses of particulate filters and calculations of gaseous and particulate emissions were conducted during the testing period. Particulate sulphate analyses were performed in February, 1988. Statistical analysis of emission results were carried out.

5. QUALITY ASSURANCE

Details of the quality assurance program can be found in Appendix D. The appendix begins with Table D.5.1 which summarizes when calibrations were performed on various pieces of equipment. Following this summary is a detailed description of the equipment and procedures used for calibration. All calibration data from the test program is summarized and the progress report in which the data was reported is indicated.

6. RESULTS

6.1 Fuel Analysis

As discussed earlier in the report, fuels B through F were analyzed by a number of Canadian laboratories. Due to the small quantity available, Fuel A (CRC fuel) could not be analyzed. Instead, the analysis from the CRC program was used.

Very extensive and detailed fuel analyses were performed for various fuel characteristics. However, the key components for the study of fuel impact on emissions were % sulphur (% wt), 90% distillation temperature (C) and % aromatics (% Vol.). These characteristics are summarized in Table 6.1.1. Figure 6.1.1 illustrates how the targeted Canadian fuels fit in with the fuel matrix tested in the CRC VE-1 program. As shown, the fuel matrix varied in sulphur from .01% to 0.52%, the 90% distillation temperature ranges from 283^{O}C to 358^{O}C and the % aromatics ranges from 22.3% to 36.6%.

The measured fuel or actual fuel characteristics are compared to the targeted characteristics in Figures 6.1.2 to 6.1.4. 90% distillation temperature results were all very close to target. Sulphur % results had differences on Fuels A, C and D. The % aromatic results were generally lower than targeted.

The complete fuel analysis matrix is summarized in Table 6.1.2. For each fuel property, the number of labs involved, the average, standard deviation, maximum and minimum are listed. The listing is also broken down by fuel.

6.2 Emission Results

Appendix E contains the data for each individual test throughout the program. Cold and hot cycle data is shown for engine emission, and engine performance. Weighted engine emissions are also shown. Results for the Cummins NTCC 400 engine are given first for Fuels A through F, followed by the DDC Series 60 engine Fuels A through F.

Tables 6.2.1 and 6.2.2 summarize the weighted emissions for each engine and fuel. Both corrected and uncorrected particulate emissions are reported for reasons detailed earlier in the report. Figures 6.2.1 through 6.2.4 summarize the fuel to fuel variations in brake specific fuel consumption and cycle work for each engine. Results show approximately 5% variation in cycle work and BSFC among the six test fuels.

The Reference Fuel F was tested at the beginning and near the end of the program for both engines. This was to ensure that the engine emissions had not drifted during the program. These repeats also addressed test to test variations. Reference fuel tests on the NTCC 400 engine are shown in Tables 6.2.3, 6.2.4 and 6.2.5. Repeat tests on October 21 and October 28, 1988, are compared statistically in Table 6.2.3. The ANOVA analysis is used to determine whether any significant differences exist between the two tests looking at emissions as well as engine performance. Analysis shows that all data in the two sets of data are within the critical limits, except for ambient humidity. Therefore, test repeatability was shown.

Tables 6.2.4 and 6.2.5 compare the October tests to the final test performed on December 1, 1988. Again, the ANOVA analysis shows all data in the four sets of data are within the critical limits with two exceptions. The December CO_2 emissions are marginally higher than the October results. Also, in Table 6.2.5, the corrected total particulate emissions are outside the statistical limits. In general, the data suggests no significant drift in engine emissions during the test program.

Repeat tests for the DDC Series 60 engine are shown in Table 6.2.6 for September 20 and November 29, 1988. The ANOVA analysis shows the data to be within critical limits, with two exceptions. Uncorrected total particulate emissions are outside the critical limits. However, applying the humidity correction brings the corrected particulate emissions well within the critical limits. The lower carbon monoxide levels in November may have been due to an analyzer problem. Overall, the data suggests no significant drift in engine emissions during the program.

Total particulate, NO_x, CO and THC emissions are plotted versus all test fuels as shown in Figure 6.2.5 - 6.2.8. As shown in Figure 6.2.5, the DDC engine can meet 1991 U.S. Emission Standards with Fuels A, C and F. Neither engine with any test fuel can meet the 1994 .1 g/bhp-hr particulate emission standard. Figures 6.2.6 - 6.2.8 show that both engines can meet the 1991, 1994 Gaseous Emission (NO_x, CO and THC) Standards using any one of the test fuels.

Tables 6.2.7 and 6.6.2.8 show the hot cycle emission summary. The tables also include fuel properties such as cetane and fuel density. These data were later used for statistical analyses.

Particulate filters collected were analyzed for sulphates as well as soluble fraction. Table 6.2.9 summarizes the results. The top portion of the Table shows the sulphate emissions for each engine and fuel and also shows the fuel sulphur. Sulphate emissions for the NTCC 400 engine varied from .05 to .13 gr/bhp-hr and for the DDC Series 60 engine varied from .04 to .22 gr/bhp-hr. Figure 6.2.9 shows positive trends between sulphate emission and fuel sulphur content.

The bottom portion of Table 6.2.9 gives the fuel sulphur % conversion to sulphate on the filter. The conversion % varied from 1.2% to 3.6% and there seems to be a negative trend between fuel sulphur content and % sulphur conversion for either engine (Figure 6.2.10). This seems to indicate that as fuel sulphur increases, sulphate emission will also increase, but the conversion from sulphur to sulphate occurs at a lower conversion %.

6.3 Correlation to CRC Results

Fuel A was identical to Fuel #7 of the VE-1 program. Emission data was obtained from CRC through DDC and Cummins for the two test engines. The VE-1 Fuel #7 data were not the final official results since the data were to be normalized according to engine testing hours as well as other testing parameters. Table 6.3.1 summarizes the results and shows the ratio between ORTECH and VE-1 data.

The emission values correlated well for the Cummins NTCC 400 engine. Particulate emissions correlated within 2%. Variability of the NO_x, CO and THC emissions was +8%, -13% and +19% respectively.

There was a -54% difference between the THC emissions for the DDC Series 60 engine. The VE-1 project measured .16 gr/bph-hr, while ORTECH measured .35 gr/bhp-hr. This may not be critical since the emission level at .35 gr/bhp.hr is still below the 1.30 gr/bhp-hr standard. Currently, there is no proposal to further reduce the THC standard (1.3 gr/bhp-hr).

The DDC Series 60 engine shows a 29% difference in particulate emissions. This seems to a high lab-to-lab variability and there is no apparent reason for the difference. Since the VE-1 data were not finalized, the ratio may be less than the results shown.

The emissions data were correlated to the VE-1 project using the ratio shown in Table 6.3.1. Table 6.3.2 and Table 6.3.3 show the correlated emission values.

6.4 Fuel Quality Impact on Emissions

In order to statistically analyze the impact of fuel quality on emissions, a linear regression analysis was performed using the SPSS/PC+ software package. The regression procedure was used to perform single and multiple linear regression analyses on aromatic content, sulphur content and 90% distillation temperature against total particulates, oxides of nitrogen, total hydrocarbons and carbon monoxide. The analyses were an attempt to generate regression equations in the following form:

$$\text{Emission (gr/bhp-hr)} = A_o + A_1 \times \text{Aromatics (\% Vol)} + A_2 \times \text{Sulphur (\%Wt)} + A_3 \times \text{90\% Pt } (^{o}C)$$

The regressions above can be used in determining the emissions impact of each of the three fuel properties. California Air Resources Board used this technique in analyzing some of the VE-1 data and results are shown in Table 6.4.1. In order for the results to be technically acceptable, the regression results must have a high correlation factor (ideal = 1) and a low standard error of estimate (ideal = 0).

The intention was to combine the data from this project and the VE-1 program to form a large emissions database. This larger database will then contain sufficient data for regression analysis. However, at the time of analysis, the VE-1 program was also in the analysis stage and the final data was not available for this project. The regression analysis was then conducted using only data shown in Tables 6.2.7 and 6.2.8.

The preliminary regression analyses, using the limited data, (hot cycle data only) show low correlation values and high standard of error of estimation. This usually is an indication that there are too many variables and insufficient data to support the regression analyses. Additional analysis, using other fuel properties (such as cetane), produced better correlation values. A decision was made to plot emissions data versus fuel properties and conduct a trend analysis.

The trend analysis will not produce a value to quantify the incremental increase in emissions per increment increase in fuel properties (e.g. gr/bph.hr per .1%S). However, this will show if there is any non-linear relationship between emissions and fuel properties. If there is a non-linear relationship, the trend analysis can also indicate approximately the fuel property values at which the emissions begin to become non-linear. Weighted emissions (particulate, NO_x, CO and THC) are plotted against the three fuel properties (aromatics, sulphur and 90% Pt), as shown in Figures 6.4.1 to 6.4.12.

7. PROJECT MANAGEMENT

Monthly progress reports were issued during the duration of the project. A number of project meetings were held at ORTECH. Appendix F contains a brief summary of the Project Meeting Minutes and Action Items.

The project was completed within the allotted budget. The completion date has been extended with approval from both EMR and PACE.

8. CONCLUSIONS AND RECOMMENDATIONS

- Particulate emissions for the DDC engine were much lower than the Cummins engine. This showed that differences in engine design had a much greater effect on particulate emissions than did fuel properties.

- Fuel D has high sulphur content (.52%), high 90% Pt. (349^{0}C) and high aromatics (34.7%) and usually yields the highest emissions.
- The Tar Sand derived fuels (B and C) did not show abnormal emission characteristics as compared to other fuels.
- Both test engines can meet '91 and '94 Gaseous Emission (NO_x, CO and THC) Standards using any one of the test fuels. Neither engine with any test fuel can meet the '94 .1 gr/bhp-hr Particulate Emission Standard. The particulate emission of the DDC engine operated on Fuel A, C and F was below the '91 .25 gr/bhp-hr Particulate Emission Standard.
- Particulate emissions for both engines increase as sulphur content, aromatic content and the 90% distillation temperatures increase.
- NO_x emissions increase very slightly as aromatics content increases for the Cummins engine and DDC engine. NO_x emissions were very close for both engines and were below 5.0 gr/bhp-hr for all test fuels.
- Emission data collected were insufficient to determine the exact emission impact individually for each of the fuel properties. There were indications that other parameters such as cetane number may also have impact on the exhaust emission.
- Additional statistical analysis should be conducted when the official VE-1 project data is available

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Emission Impacts of Current and Possible Future Canadian Fuels on Heavy Duty Diesel Engines - For PACE and EMR

TABLE 1.1 - Summary of Canadian and U.S. Heavy-Duty Diesel Emissions (Proposed and Regulated) Standard (Transient Certification Procedure)

Emissions g/bhp-hr	Regulated Canadian 1986 Can.	Regulated Canadian and U.S. 1986 U.S.	1988 (Dec.1) Can.	1990 U.S.	Regulated U.S. Proposed 1991	Canadian 1994
CO	40	15.5	15.5	15.5	15.5	15.5
HC)		1.3	1.3	1.3	1.3	1.3
NO_x)	16	10.7	6.0	6.0	5.0	5.0
Particulates		-	.60	.60	.25	.10
					.10 (bus)	

Emissions g/MJ	Regulated Canadian 1986 Can.	Regulated Canadian and U.S. 1986 U.S.	1988 (Dec.1) Can.	1990 U.S.	Regulated U.S. Proposed 1991	Canadian 1994
CO	14.88	5.77	5.77	5.77	5.77	5.77
HC)		.48	.48	.48	.48	.48
NO_x)	5.95	3.98	2.23	2.23	1.85	1.85
Particulates		-	.22	.22	.09	.037
					037 (bus)	

TABLE 1.2

Committee Members

Petroleum Committee

Dave Steere	Esso Petroleum Canada
Robert Bagnall	Petro Canada Products
Ken Mitchell	Shell Canada Ltd.
Ed Clarke	Texaco Canada Inc.
W. Boyles	PACE (Texaco)

Government Committee

Kim Smith	Energy, Mines & Resources
Andrew Beregszaszy	Energy, Mines & Resources
Liviu Vancea	Energy, Mines & Resources
Gary Webster	National Research Council
Nicolas Ostrouchov	Environment Canada
Lui Hrobelsky	Transport Canada

Engine Manufacturers's Committee

Shirish Shimpi	Cummins Engine Co.
Richard Winsor	Detroit Diesel Corp.

TABLE 1.3

Canadian Test Fuel Matrix

Fuel #	A	B	C	D	E
Composition (Approx. Vol. %)	(1)				
Synthetic Dist.		30	-	-	-
Upgraded Syn. Dist.	-	-	100	-	-
Conv. Straight Run		50	-	75	75
Conv. Cat Cracked		20	-	25	25
Target Properties					
Aromatics, Vol. %	28.4	40	25	45	40
Sulphur, Wt.%	0.15	0.2	0.08	0.4	0.4
90% Pt., ^{o}C	317	340	340	340	360

(1) CRC Reference Fuel #7.

TABLE 6.1.1

FUEL ANALYSIS SUMMARY

FUEL	%S (WT%)*	90 %Pt (^{O}C)**	AROMATICS (% VOL)***
A	.15	317	28.4
B	.20	329	36.6
C	.01	336	22.3
D	.52	349	34.7
E	.40	358	30.1
F	.19	283	25.5

* (D4294)
** (D86)
*** (FIA D1319)

TABLE 6.1.2

	Fuel A					Fuel B					Fuel C					
	# of Labs	Avg	Std Dev	Cov	Min	Max	# of Labs	Avg	Std Dev	Cov	Min	Max	# of Labs	Avg	Std Dev	Cov	Min	Max
DENSITY (D1298), Kg/L	1	0.8511	--	--	--	--	5	0.8717	0.002	0.229	0.8706	0.8728	5	0.8649	0.0017	0.196	0.8639	0.8656
Kinematic Visc (D445), cst	1	2.84	--	--	--	--	5	3.65	0.11	3.01	3.60	3.71	5	3.88	0.05	1.29	3.87	3.92
Distillation (D86),°C			--	--	--	--												
IBP	1	176	--	--	--	--	5	194	14	7.216	187	201	5	193	6	3.108	192	198
10%	1	213	--	--	--	--	5	243	9	3.704	238	247	5	228	8	3.508	225	233
50%	1	288	--	--	--	--	5	290	2	0.689	289	291	5	286	4	1.398	284	288
90%	1	317	--	--	--	--	5	329	1	0.303	329	330	5	336	4	1.190	334	338
FBP	1	341	-	-	-	-	5	345	2	0.579	344	346	5	353	6	1.699	349	355
Recovery, % Vol.	1	99	--	--	--	--	5	98.2	0.5	5.091	98	98.5	5	98.2	0.9	0.916	97.6	98.5
Residue, % Vol.	1	0.4	--	--	--	--	5	1.2	1.53	127.5	0.7	1.8	5	1.22	1	81.967	0.7	1.7
Flash Point (D93), °C	1	63	--	--	--	--	5	73	5	6.849	71	76	5	76	3	3.947	74	77
Smoke Pt. (D1322)	1	18.1	--	--	--	--	4	12.5	2.3	18.4	11.5	13.8	3	17.1	6.2	36.257	13.5	19.7
Aniline Point, (D611)°C	1	60.8	--	--	--	--	5	58.2	1.8	2.749	57.4	59	5	68.9	1.1	1.598	68.4	69.5
Refractive Index, N	1	1.4713	--	--	--	--	4	1.484	0.012	0.808	1.4745	1.4865	4	1.471	0.012	0.815	1.4617	1.4732
ASTM Cetane Index (D976-66/IP 218)	1	47.2	--	--	--	--	5	48.4	0.8	1.724	48.2	47	5	48.2	4	8.298	45	49
ASTM Cetane Index (D976-80)	1	46.8	--	--	--	--	5	44.8	0.9	2.008	44.6	45.5	5	46.2	1.5	3.246	45	48.5
CQSB Cetane Index	1	43.6	--	--	--	--	4	43.7	0.7	1.601	41.7	42.4	5	48.1	0.8	1.629	46.7	49.5
Cetane No. (D613)	1	46.6	--	--	--	--	3	43.9	3.2	7.289	42.3	45.5	3	46	8.7	14.565	43.1	49.8
Hydrogen, % mass (D3701)	1	13.34	--	--	--	--	3	12.53	0.47	3.75	12.18	12.65	3	13.21	0.55	4.163	12.81	13.36
Nitrogen (chemiluminescence),ppm	1	229	--	--	--	--	2	129	5	3.875	126	131	2	3.7	1.8	48.648	2.8	4.6
Sulphur (D4294), % mass	1	0.15	--	--	--	--	5	0.2	0.05	2.5	0.18	0.23	5	0.01	0.027	27	0	0.027
Sulphur (chemiluminescence) ppm	1	1758	--	--	--	--	1	2137	-	-	-	-	1	10.2	-	-	-	-
Average Molecular Wt.(P-NMR)	--	-	--	--	--	--	1	473	-	-	-	-	1	1330	-	-	-	-
Ht. of Combustion (D240), Gross BTU/LB	1	19857	--	--	--	--	2	19470	25	0.128	19457	19482	2	19712	34	0.172	19695	19729
Ramsbottom Carbon Residue, 10% Bottoms	1	0.11	--	--	--	--	1	0.10	-	-	-	-	1	0.11	-	-	-	-
Cloud Point, °C	1	-18	--	--	--	--	5	-8	2	25	-7	-9	5	-30	4	13.333	-27	-31
Pour Point, °C	1	-27	--	--	--	--	5	-12	11	91.666	-9	-21	3	-53	6	11.320	-51	-57
Bromine Number	1	0.6	--	--	--	--	2	0.64	0.09	14.06	0.6	0.69	2	0.6	0.05	8.333	0.55	0.6
Maleic Anhydride Value	1	<0.5	--	--	--	--	1	< 0.5	-	-	-	-	1	<0.5	-	-	-	-
Liquid Chrom (D2007) % Mass																		
Saturates							1	59.8	0	-	59.8	59.8	1	83.3	0	-	83.3	83.3
Polars CPDS							1	0.9	0	-	0.9	0.9	1	0.1	0	-	0.1	0.1
Aromatics							1	39.3	0	-	39.3	39.3	1	16.6	0	-	16.6	16.6
FIA (D1319), % Vol.																		
Saturates	3	70.5	4.5	6.382	66.8	73.3	4	60.4	8.5	10.76	56.5	69	4	80	4.4	5.5	77.8	82.2
Olefins	3	1.1	0.7	63.636	0.8	1.5	4	2.9	4.7	162..06	0.8	5.5	4	3.2	3.2	100	1.3	4.5
Aromatics	3	28.4	3.8	13.38	25.9	29.7	4	36.6	5.1	13.93	33.1	38.2	4	22.3	28	125.56	14.2	38.2
Mass Spec (PONA) +, % mass																		
Paraffins	1	29.02	0	-	29.02	29.02	3	22.5	10.4	46.22	17.6	28	3	12.7	3.23	25.433	11.17	14.4
Olefins							1	0	0	-	0	0	1	13.8	0	-	13.8	13.8
Naphthenes							2	33.25	11.5	34.586	27.5	39	2	51.8	12.6	24.324	45.5	58.1
Aromatics	1	24.6	0	-	24.6	24.6	3	41.6	7.61	18.293	36.89	44.5	3	23.6	14.4	61.016	15.12	29.5
Proton NMR, % mass																		
Paraffins				-	-	-	1	61.4	-	-	-	-	1	79.82	-	-	-	-
Aromatics				-	-	-	1	38.6	-	-	-	-	1	20.18	-	-	-	-
Carbon Groups																		
% C4-alpha - alkyl CH2, CH3							2	9.27	1.26	13.592	8.64	9.9	2	3.71	1.55	41.778	2.94	4.49
%C2-paraffinic CH, CH2				-	-	-	2	51.28	4.77	9.301	48.89	53.66	2	64.23	4.22	6.57	62.12	66.34
%C3-paraffinic CH3				-	-	-	2	15.06	1.42	9.428	14.35	15.77	2	22.16	3.34	15.072	20.49	23.83
%CA-aromatic ring carbon				-	-	-	2	24.4	4.93	20.204	21.93	26..86	2	9.90	8.01	80.707	6.89	12.90
PONA by Supercritical Fluid (EMR)				-	-	-	1	38.3	-	-	-	-	1	14.2	-	-	-	-
AROM by Supercritical Fluid (CCRL)				-	-	-	1	40.3	-	-	-	-	1	15.8	-	-	-	-

Fuel Properties of EMR/PACE Fuel Matrix

TABLE 6.1.2

	Fuel D						Fuel E						Fuel F					
	# of Labs	Avg	Std Dev	Cov	Min	Max	# of Labs	Avg	Std Dev	Cov	Min	Max	# of Labs	Avg	Std Dev	Cov	Min	Max
DENSITY (D1266), Kg/L	5	0.8707			0.8692	0.8716	5	0.8625	0.0019	0.22	0.8613	0.8632	5	0.8309	0.0042		0.8295	0.8337
Kinematic Visc (D445), cst	5	3.01	0.033	1.09	2.997	3.030	5	3.30	0.040		3.270	3.310	5	1.73	0.10		1.7000	1.8000
Distillation (D86),°C																		
IBP	5	178	7	3.91	175	182	5	178	10	5.617	173	183	5	162	13	8.024	156	169
10%	5	224	20	8.928	207	227	5	212	13	6.132	207	220	5	189	6	3.174	187	193
50%	5	278	8	2.877	276	284	5	286	21	7.342	276	297	5	234	9	3.846	231	240
90%	5	349	11	3.151	346	357	5	358	27	7.541	348	375	5	283	13	4.593	280	293
FBP	5	376	8	2.127	374	378	5	380	19	5	375	394	5	312	14	4.487	307	321
Recovery, % Vol.	5	97.8	0.5	0.511	97.5	98	5	97.7	0.8	0.818	97.2	98	5	98.4	1.8	1.829	97.2	99
Residue, % Vol.	5	1.4	1	71.428	1	2	5	1.4	0.4	28.571	1.5	1.9	5	1.1	1.0	90.909	0.5	1.5
Flash Point (D93), °C	5	67	5	7.462	65	70	5	66	7	10.606	62	69	5	50	5	10	46	53
Smoke Pt. (D1322)	4	12.3	2.4	19.512	11	13.4	4	13.4	4.1	30.597	11.5	15.6	3	18.2	4.6	28.395	14.5	19.1
Aniline Point, (D611)°C	5	58	2	3.571	55	57	5	63.4	0.1	0.157	63	63.4	5	58.1	1.6	2.753	57.4	59
Refractive Index, N	4	1.4888	0.013	0.873	1.4782	1.4911	4	1.4805	0.012	0.810	1.4703	1.4827	4	1.4818	0.012	0.820	1.4519	1.4841
ASTM Cetane Index (D976-66/IP 218)	5	44.1	2.7	6.122	42	45.3	5	49	5.1	10.408	46.2	51.3	5	47.6	4.5	9.453	45.5	50
ASTM Cetane Index (D976-80)	5	43.3	1.7	3.926	42.5	44.2	5	46.7	3.2	6.852	45	48.2	5	45.4	2.9	6.387	43.9	48.8
CGSB Cetane Index	5	40.9	1.4	3.422	40.1	41.5	5	45.7	1.1	2.407	45.2	46.3	5	43.1	1.2	2.784	42.5	43.7
Cetane No. (D613)	3	41.9	3.1	7.398	40.8	43.9	3	43.9	4.3	9.794	41.9	48.2	3	41.9	3.5	8.353	41.5	45
Hydrogen, % mass (D3701)	3	12.18	0.49	4.019	11.82	12.31	3	12.81	0.67	5.313	12.14	12.81	3	12.85	0.75	5.836	12.56	13.31
Nitrogen (chemiluminescence),ppm	2	217	9	4.147	212	221	2	234	18	7.692	225	243	2	47	5.6	11.914	44.4	50
Sulphur (D4294), % mass	4	0.52	0.06	11.538	0.45	0.58	5	0.40	0.04	10	0.38	0.42	5	0.19	0.12	63.157	0.12	0.24
Sulphur (chemiluminescence) ppm	1	5203	-	-	-	-	1	3813	-	-	-	-	1	1058	-	-	-	-
Average Molecular Wt.(P-NMR)	1	430	-	-	-	-	1	534	-	-	-	-	1	583	-	-	-	-
Ht. of Combustion (D240), Gross BTU/LB	2	19366	9	0.046	19361	19370	2	19496	16	0.082	19488	19504	2	19667	29	0.147	19652	19681
Ramsbottom Carbon Residue, 10% Bottoms	1	0.11	-	-	-	-	1	0.10	-	-	-	-	1	0.11	-	-	-	-
Cloud Point, °C	5	-1	3	200	0	-3	4	-9	2	22.222	-8	-10	4	-33	3	9.09	-32	-35
Pour Point, °C	5	-15	12	80	9	-21	5	-29	13	44.827	-23	-36	5	-34	3	8.823	-33	-36
Bromine Number	2	1.5	0.24	16	1.4	1.65	2	0.9	0.1	11.111	0.8	0.9	2	1	0.37	37	0.8	1.27
Maleic Anhydride Value	1	<0.5	-	-	-	-	1	<0.5	-	-	-	-	1	<0.5	-	-	-	-
Liquid Chrom (D2007) % Mass																		
Saturates	1	58	-	-	-	-	1	64.4	-	-	-	-	1	69.7	-	-	-	-
Polars CPDS	1	0.6	-	-	-	-	1	0.7	-	-	-	-	1	0.2	-	-	-	-
Aromatics	1	41.4	-	-	-	-	1	34.9	-	-	-	-	1	30.1	-	-	-	-
FIA (D1319), % Vol.																		
Saturates	4	60.7	8.8	14.497	57	65.8	4	66.6	5.1	12.162	61.9	70	4	73.6	2.7	3.658	73	75.1
Olefins	4	0.95	0.7	82.352	0.4	1.1	4	0.85	0.7	82.352	0.4	1.1	4	0.7	0.5	714.28	0.5	1
Aromatics	4	34.7	12.3	35.446	25.9	38.2	4	30.1	7	23.255	27	34	4	25.5	1.7	6.666	24.4	26.1
Mass Spec (PONA) +, % mass																		
Paraffins	3	27.1	12.7	46.863	18.2	31.9	3	29.9	1.6	5.351	29.2	30.8	3	36.7	5.9	16.076	34.5	40.4
Olefins	1	0	-	-	-	-	1	6.1	-	-	-	-	1	0.1	-	-	-	-
Naphthenes	2	32	17.1	53.437	23	40.1	2	33.4	6	23..952	29.4	37.4	2	34.9	11.6	33.237	29.6	40.2
Aromatics	3	41.5	8.3	20	37.6	46.1	3	33.3	11.6	34.834	29.3	40.9	3	28.8	11.4	39.583	23.9	35.3
Proton NMR, % mass																		
Paraffins	1	57.39	-	-	-	-	1	66.73	-	-	-	-	1	70.54	-	-	-	-
Aromatics	1	42.61	-	-	-	-	1	33.27	-	-	-	-	1	29.46	-	-	-	-
Carbon Groups																		
% C6-alpha - alkyl CH2, CH3	2	9.65	2.1	21.761	8.8	10.7	2	7.56	1.01	13.359	7.01	8.11	2	7.12	1.18	16.573	6.53	7.71
%C2-paraffinic CH, CH2	2	47.81	3.11	6.504	46.25	49.36	2	52.48	2.79	5.316	51.08	23.87	2	53.45	2.46	4..602	52.22	54.68
%C3-paraffinic CH3	2	13.87	2.87	20.692	12.8	14.95	2	16.84	2.54	15.083	15.27	17.81	2	18.93	2.4	5.282	17.73	20.13
%CA-aromatic ring carbon	2	28.99	3.79	13.073	27.09	30.88	2	23.43	4.23	18.053	21.31	25.54		20.5	3.88	17.951	18.68	22.34
PONA by Supercritical Fluid (EMR)	1	40.2	-	-	-	-	1	31.8	-	-	-	-	1	27.3	-	-	-	-
AROM by Supercritical Fluid (OCRL)	1	41.3	-	-	-	-	1	33.9	-	-	-	-	1	28.1	-	-	-	-

TABLE 6.2.1

CUMMINS NTCC400

WEIGHTED MODIFIED TRANSIENT EMISSION SUMMARY
(gr/bhp.hr)

FUEL	A	B	C	D	E	F	F	F
NO_x	4.22	4.50	4.12	4.58	4.39	4.42	4.59	4.40
CO	2.66	2.27	2.75	2.38	2.16	2.61	2.46	2.55
THC	.48	.42	.41	.46	.42	.49	.48	.50
PART.(UNCOR)	.49	.51	.48	.55	.54	.43	.40	.43
PART.(COR)	.52	.57	.50	.61	.60	.46	.44	.48
SOF (UNCOR)	.06	.09	.08	.10	.13	.05	.05	.05
SOF (COR)	.06	.10	.08	.11	.14	.05	.05	.05

TABLE 6.2.2

DDC SERIES 60 (6R-544)

WEIGHTED MODIFIED TRANSIENT EMISSION SUMMARY
(gr/bhp.hr)

FUEL	A	B	C	D	E	F	F
NO_x	4.53	4.65	4.34	4.77	4.56	3.91	4.51
CO	2.41	2.66	2.11	2.45	2.37	2.38	2.36
THC	.35	.41	.15	.39	.30	.62	.51
PART.(UNCOR)	.21	.28	.17	.30	.28	.20	.19
PART.(COR)	.22	.30	.19	.33	.31	.20	.21
SOF (UNCOR)	.08	.15	.05	.14	.10	.08	.08
SOF (COR)	.09	.16	.05	.16	.11	.08	.09

TABLE 6.2.3 NTCC 400 Reference Fuel Emission Comparison 1.

Cummins NTCC400 Modified EPA Transient Cycle data
******Official Tests - Fuel F (ORTECH Reference)

	Oct 21, 1988				Oct 28, 1988			----ANOVA----				
Emission	DF	AVG	STD	SOS	DF	AVG	STD	SOS	DF	SOS	Sd**2	t-stat	t-crit	Signif.
BSNOX	4	4.45	0.07	0.021	5	4.63	0.05	0.0113	9	0.032	0.012	-1.69	1.83	yes
BSCO	4	2.58	0.07	0.020	5	2.40	0.07	0.0235	9	0.043	0.015	1.45	1.83	yes
BSTHC	4	0.50	0.02	0.001	5	0.48	0.01	0.0007	9	0.002	0.000	0.58	1.83	yes
BSCO2	4	642	8	257	5	631	8	303	9	559.6	205.2	0.71	1.83	yes
TOTAL -UNCOR	4	0.00	0.00	0	5	0.00	0.00	0.0000	9	0	0		1.83	
BSPART-CORR	4	0.00	0.00	0	5	0.00	0.00	0.0000	9	0	0		1.83	
Avg rpm	4	1234	1	7	5	1235	1	3	9	10	4	-0.10	1.83	yes
Avg Torq	4	253	1	1	5	253	1	2	9	3	1	-0.07	1.83	yes
Tot Fuel	4	11.8	0.1	0.0	5	11.7	0.3	0.4	9	0.5	0.2	0.15	1.83	yes
Work	4	27.6	0.1	0.0	5	27.5	0.1	0.1	9	0.1	0.0	0.49	1.83	yes
BSFC	4	0.427	0.00	0.0	5	0.427	0.010	0.000	9	0.000	0.000	0.04	1.83	yes
H -grains h20/lb dry air	4	43.5	2.9	34.2	5	25.6	4.9	120.5	9	154.7	56.7	2.37	1.83	no

TABLE 6.2.4 NTCC 400 Reference Fuel Emission Comparison 2.

Cummins NTCC400 Modified EPA Transient Cycle data
********Official Tests - Fuel F (ORTECH Reference)**

	Dec 1, 1988				Oct 21, 1988				ANOVA				
Emission	DF	AVG	STD	SOS	DF	AVG	STD	SOS	DF	SOS	Sd**2	t-stat	t-crit	Signif
BSNOX	5	4.45	0.08	0.035	4	4.45	0.07	0.0217	9	0.057	0.020	0.00	1.83	yes
BSCO	5	2.51	0.05	0.013	4	2.58	0.07	0.0201	9	0.033	0.012	-0.66	1.83	yes
BSTHC	5	0.49	0.01	0.000	4	0.50	0.02	0.0014	9	0.001	0.000	-0.18	1.83	yes
BSCO2	5	676	11	578	4	642	8	257	9	835.0	306.1	1.93	1.83	no
TOTAL -UNCOR	5	0.42	0.01	0.000	4	0.43	0.03	0.0033	9	0.003	0.001	-0.37	1.83	yes
BSPART-CORR	5	0.47	0.01	0.000	4	0.46	0.03	0.0043	9	0.004	0.001	0.06	1.83	yes
Avg rpm	5	1233	1	1	4	1235	1	7	9	9	3	-1.13	1.83	yes
Avg Torque	5	250	1	11	4	253	1	1	9	12	4	-1.36	1.83	yes
Tot Fuel	5	11.8	0.1	0.0	4	11.8	0.1	0.0	9	0.1	0.0	-0.19	1.83	yes
Work	5	27.3	0.1	0.1	4	27.6	0.1	0.0	9	0.1	0.0	-1.26	1.83	yes
BSFC	5	0.431	0.00	0.0	4	0.428	0.003	0.000	9	0.000	0.000	0.46	1.83	yes
H -grains h20/lb dry air	5	25.9	1.2	7.7	4	43.5	2.9	34.2	9	41.9	15.4	-4.51	1.83	no

TABLE 6.2.5 NTCC 400 REference Fuel Emission Comparison 3.

Cummins NTCC400 Modified EPA Transient Cycle data
xxxxxxOfficial Tests - Fuel F (ORTECH Reference)

Emission	Dec 1, 1988 DF	AVG	STD	SOS	Oct 28, 1988 DF	AVG	STD	SOS	ANOVA DF	SOS	Sdxx2	t-stat	t-crit	Signif
BSNOX	5	4.45	0.08	0.036	5	4.63	0.05	0.0113	10	0.046	0.015	-1.48	1.81	yes
BSCO	5	2.51	0.05	0.013	5	2.40	0.07	0.0235	10	0.036	0.012	0.99	1.81	yes
BSTHC	5	0.49	0.01	0.000	5	0.48	0.01	0.0007	10	0.000	0.000	0.67	1.81	yes
BSCO2	5	676	11	578	5	631	8	303	10	880.4	293.4	2.57	1.81	no
TOTAL -UNCOR	5	0.42	0.01	0.000	5	0.38	0.01	0.0010	10	0.001	0.000	1.76	1.81	yes
BSPART-CORR	5	0.47	0.01	0.000	5	0.43	0.01	0.0007	10	0.001	0.000	2.14	1.81	no
Avg rpm	5	1233	1	1	5	1235	1	3	10	4	1	-1.81	1.81	yes
Tot Fuel	5	11.8	0.1	0.0	5	11.7	0.3	0.4	10	0.5	0.2	0.12	1.81	yes
Work	5	27.3	0.1	0.1	5	27.5	0.1	0.1	10	0.2	0.1	-0.61	1.81	yes
BSFC	5	0.431	0.00	0.0	5	0.427	0.010	0.000	10	0.000	0.000	0.31	1.81	yes
H -grains h20/lb dry air	5	25.9	1.2	7.7	5	25.6	4.9	120.5	10	128.2	42.7	0.03	1.81	yes

TABLE 6.2.6 Baseline Emission Comparison - Fuel F.

DDC Series 60 Modified EPA Transient Cycle data
xxxxxxOfficial Tests - Fuel F (ORTECH Reference)

		Nov 29, 1988				Sept 20, 1988			----ANOVA----					
Emission	DF	AVG	STD	SOS	DF	AVG	STD	SOS	DF	SOS	Sd**2	t-stat	t-crit	Signif.
BSNOX	5	4.51	0.03	0.003	6	4.66	0.12	0.0887	11	0.092	0.028	-0.87	1.80	yes
BSCO	5	2.23	0.04	0.009	6	2.43	0.05	0.0127	11	0.021	0.006	-2.43	1.80	no
BSTHC	5	0.40	0.01	0.000	6	0.46	0.03	0.0059	11	0.006	0.001	-1.19	1.80	yes
BSCO2	5	593	4	67	6	597	10	610	11	676.3	209.3	-0.21	1.80	yes
TOTAL -UNCOR	5	0.18	0.00	0.000	6	0.21	0.01	0.0003	11	0.000	0.000	-2.53	1.80	no
BSPART-CORR	5	0.20	0.00	0.000	6	0.20	0.01	0.0002	11	0.000	0.000	-0.39	1.80	yes
Avg rpm	5	989	2	29	6	982	3	58	11	87	27	1.46	1.80	yes
Avg Torque	5	237	0	1	6	234	1	3	11	4	1	2.82	1.80	yes
Tot Fuel	5	8.1	0.0	0.0	6	8.1	0.0	0.0	11	0.0	0.0	0.39	1.80	yes
Work	5	21.4	0.1	0.0	6	21.2	0.1	0.1	11	0.1	0.0	1.06	1.80	yes
BSFC	5	0.378	0.00	0.0	6									
H -grains h20/lb dry air	5	25.6	0.7	2.3	6	81.6	4.9	145.9	11	148.2	45.9	-8.27	1.80	no

Table 6.2.7
Emission Database NTCC 400
Hot Cycles Only

Fuel #	% S	% Aro	90 DT	Test Date	NOX	CO	THC	CO2	PART UN	PART COR	Work	Hum	DenS.	Cetane #
F	0.19	25.5	283	01-Dec-88	4.31	2.57	0.50	690	0.43	0.48	27.4	25.2	0.831	41.9
F	0.19	25.5	283	01-Dec-88	4.38	2.56	0.50	685	0.43	0.47	27.3	25.2	0.831	41.9
F	0.19	25.5	283	01-Dec-88	4.44	2.52	0.48	657	0.41	0.46	27.6	25.2	0.831	41.9
F	0.19	25.5	283	01-Dec-88	4.48	2.45	0.49	669	0.42	0.46	27.2	25.2	0.831	41.9
F	0.19	25.5	283	01-Dec-88	4.52	2.50	0.49	674	0.41	0.46	27.2	25.7	0.831	41.9
F	0.19	25.5	283	01-Dec-88	4.56	2.43	0.49	678	0.42	0.46	27.2	28.6	0.831	41.9
C	0.01	22.3	336	04-Nov-88	4.09	2.70	0.40	644	0.46	0.49	28.2	48.3	0.865	46.0
C	0.01	22.3	336	04-Nov-88	4.21	2.70	0.39	648	0.48	0.50	28.1	56.7	0.865	46.0
C	0.01	22.3	336	04-Nov-88	4.29	2.77	0.36	636	0.47	0.48	28.1	61.5	0.865	46.0
C	0.01	22.3	336	04-Nov-88	4.10	2.79	0.42	649	0.46	0.48	28.1	62.7	0.865	46.0
C	0.01	22.3	336	04-Nov-88	4.11	2.75	0.41	657	0.46	0.48	28.2	54.4	0.865	46.0
C	0.01	22.3	336	04-Nov-88	4.14	2.79	0.41	620	0.47	0.48	28.1	58.5	0.865	46.0
A	0.15	28.4	317	10-Nov-88	4.21	2.80	0.48	645	0.50	0.51	27.1	60.6	0.851	46.6
A	0.15	28.4	317	10-Nov-88	4.25	2.72	0.49	662	0.48	0.50	27.0	54.2	0.851	46.6
A	0.15	28.4	317	10-Nov-88	4.26	2.60	0.47	666	0.47	0.50	27.1	47.3	0.851	46.6
A	0.15	28.4	317	10-Nov-88	4.26	2.58	0.47	661	0.47	0.50	27.2	40.5	0.851	46.6
A	0.15	28.4	317	10-Nov-88	4.32	2.51	0.47	646	0.46	0.50	27.2	37.6	0.851	46.6
B	0.20	36.6	329	17-Nov-88	4.78	2.25	0.41	689	0.49	0.51	27.1	52.8	0.872	43.9
B	0.20	36.6	329	17-Nov-88	4.52	2.23	0.40	670	0.50	0.56	27.2	25.4	0.872	43.9
B	0.20	36.6	329	17-Nov-88	4.48	2.25	0.41	675	0.51	0.56	27.1	23.5	0.872	43.9
B	0.20	36.6	329	17-Nov-88	4.58	2.22	0.41	676	0.51	0.56	27.0	25.4	0.872	43.9
B	0.20	36.6	329	17-Nov-88	4.55	2.18	0.41	672	0.50	0.55	27.2	23.9	0.872	43.9
B	0.20	36.6	329	17-Nov-88	4.57	2.18	0.41	675	0.50	0.56	27.1	23.9	0.872	43.9
D	0.52	34.7	349	24-Nov-88	4.66	2.42	0.44	695	0.54	0.59	27.5	28.8	0.863	41.9
D	0.52	34.7	349	24-Nov-88	4.60	2.33	0.43	697	0.53	0.59	27.4	27.3	0.863	41.9
D	0.52	34.7	349	24-Nov-88	4.65	2.24	0.46	683	0.55	0.60	27.5	27.3	0.863	41.9
D	0.52	34.7	349	24-Nov-88	4.67	2.25	0.44	695	0.53	0.58	27.5	29.4	0.863	41.9
D	0.52	34.7	349	24-Nov-88	4.63	2.29	0.44	685	0.55	0.60	27.5	29.4	0.863	41.9
D	0.52	34.7	349	24-Nov-88	4.57	2.31	0.44	689	0.54	0.59	27.5	28.6	0.863	41.9
E	0.40	30.1	358	08-Dec-88	4.55	2.15	0.39	701	0.51	0.57	27.7	27.7	0.863	43.9
E	0.40	30.1	358	08-Dec-88	4.44	2.15	0.39	681	0.54	0.60	24.0	27.7	0.863	43.9
E	0.40	30.1	358	08-Dec-88	4.39	2.11	0.41	690	0.52	0.58	20.8	27.9	0.863	43.9
E	0.40	30.1	358	08-Dec-88	4.42	2.05	0.41	693	0.51	0.57	20.6	27.8	0.863	43.9
E	0.40	30.1	358	08-Dec-88	4.37	2.07	0.41	697	0.52	0.58	20.5	28.0	0.863	43.9
E	0.40	30.1	358	08-Dec-88	4.41	2.03	0.40	694	0.51	0.57	20.5	27.8	0.863	43.9
AVG					4.42	2.39	0.42	672	0.50	0.54	26.4	37.8	0.863	44.4
STD					0.19	0.26	0.03	21	0.03	0.04	2.4	13.8	0.006	1.7
COV					4	11	7	3	5	8	9	36	1	4
MIN	0.01	22.3	317		4.09	2.03	0.36	620	0.46	0.48	20.5	23.5	0.851	41.9
MAX	0.52	36.6	358		4.78	2.80	0.49	701	0.55	0.60	28.2	62.7	0.872	46.6

Table 6.2.8
Emission Database DDC 6R544
Hot Cycles Only

Fuel #	% S	% Aro	90 DT	Test Date	NOX	CO	THC	CO2	UNC PART	COR PART	Work	Hum.	Den	Cetane #
F	0.19	25.5	283	20-Sep-88	4.45	2.50	0.49	609	0.20	0.20	21.0	82.1	0.831	41.9
F	0.19	25.5	283	20-Sep-88	4.55	2.44	0.49	583	0.20	0.20	21.2	77.2	0.831	41.9
F	0.19	25.5	283	20-Sep-88	4.68	2.47	0.47	583	0.22	0.21	21.2	77.1	0.831	41.9
F	0.19	25.5	283	20-Sep-88	4.69	2.43	0.45	598	0.20	0.20	21.2	77.1	0.831	41.9
F	0.19	25.5	283	20-Sep-88	4.78	2.37	0.42	604	0.21	0.21	21.3	87.3	0.831	41.9
F	0.19	25.5	283	20-Sep-88	4.79	2.38	0.41	602	0.21	0.21	21.3	88.9	0.831	41.9
A	0.15	28.4	317	15-Oct-88	4.50	2.21	0.31	603	0.20	0.21	21.9	44.3	0.851	46.6
A	0.15	28.4	317	15-Oct-88	4.51	2.21	0.30	604	0.19	0.21	21.9	42.2	0.851	46.6
A	0.15	28.4	317	15-Oct-88	4.48	2.21	0.29	602	0.20	0.22	21.9	43.5	0.851	46.6
A	0.15	28.4	317	15-Oct-88	4.46	2.22	0.30	607	0.19	0.21	21.8	45.8	0.851	46.6
A	0.15	28.4	317	15-Oct-88	4.49	2.26	0.30	604	0.20	0.21	21.7	46.7	0.851	46.6
B	0.20	36.6	329	08-Nov-88	4.69	2.23	0.35	619	0.22	0.24	22.7	44.8	0.872	43.9
B	0.20	36.6	329	08-Nov-88	4.62	2.70	0.31	600	0.23	0.24	22.7	42.5	0.872	43.9
B	0.20	36.6	329	08-Nov-88	4.63	2.46	0.31	596	0.22	0.23	22.7	44.8	0.872	43.9
B	0.20	36.6	329	08-Nov-88	4.59	2.47	0.31	591	0.23	0.24	22.6	41.8	0.872	43.9
B	0.20	36.6	329	08-Nov-88	4.57	2.60	0.30	611	0.24	0.26	22.8	42.7	0.872	43.9
B	0.20	36.6	329	08-Nov-88	4.59	2.53	0.30	589	0.23	0.24	23.1	43.8	0.872	43.9
C	0.01	22.3	336	15-Nov-88	4.34	2.07	0.13	597	0.17	0.18	22.7	34.9	0.865	46.0
C	0.01	22.3	336	15-Nov-88	4.20	1.90	0.15	585	0.17	0.19	22.7	29.3	0.865	46.0
C	0.01	22.3	336	15-Nov-88	4.29	1.97	0.15	585	0.17	0.19	22.8	33.6	0.865	46.0
C	0.01	22.3	336	15-Nov-88	4.31	1.94	0.15	590	0.17	0.19	22.7	32.2	0.865	46.0
C	0.01	22.3	336	15-Nov-88	4.31	1.98	0.14	589	0.17	0.19	22.7	35.6	0.865	46.0
C	0.01	22.3	336	15-Nov-88	4.29	2.02	0.16	591	0.17	0.19	22.7	36.1	0.865	46.0
D	0.52	34.7	349	22-Nov-88	4.74	2.25	0.33	605	0.27	0.30	22.6	27.2	0.871	41.9
D	0.52	34.7	349	22-Nov-88	4.75	2.18	0.29	601	0.27	0.30	22.7	27.3	0.871	41.9
D	0.52	34.7	349	22-Nov-88	4.70	2.21	0.30	606	0.27	0.30	22.7	26.3	0.871	41.9
D	0.52	34.7	349	22-Nov-88	4.72	2.20	0.29	595	0.27	0.29	22.7	26.4	0.871	41.9
D	0.52	34.7	349	22-Nov-88	4.75	2.23	0.31	596	0.27	0.30	22.8	28.4	0.871	41.9
D	0.52	34.7	349	22-Nov-88	4.77	2.22	0.32	600	0.29	0.32	22.7	28.4	0.871	41.9
F	0.19	25.5	283	29-Nov-88	4.48	2.24	0.40	592	0.18	0.20	21.4	25.6	0.831	41.9
F	0.19	25.5	283	29-Nov-88	4.53	2.30	0.42	598	0.18	0.20	21.3	25.6	0.831	41.9
F	0.19	25.5	283	29-Nov-88	4.55	2.24	0.40	594	0.18	0.20	21.4	26.8	0.831	41.9
F	0.19	25.5	283	29-Nov-88	4.49	2.21	0.40	596	0.18	0.20	21.5	24.9	0.831	41.9
F	0.19	25.5	283	29-Nov-88	4.50	2.17	0.39	587	0.19	0.21	21.5	25.0	0.831	41.9
E	0.40	30.1	358	06-Dec-88	4.56	2.20	0.26	602	0.24	0.26	22.7	32.9	0.863	43.9
E	0.40	30.1	358	06-Dec-88	4.50	2.19	0.25	603	0.24	0.26	22.8	32.9	0.863	43.9
E	0.40	30.1	358	06-Dec-88	4.54	2.17	0.24	596	0.24	0.26	22.7	31.6	0.863	43.9
E	0.40	30.1	358	06-Dec-88	4.43	2.17	0.28	602	0.25	0.27	22.8	29.0	0.863	43.9
E	0.40	30.1	358	06-Dec-88	4.52	2.20	0.26	601	0.25	0.27	22.7	33.1	0.863	43.9
AVG					4.53	2.22	0.28	598	0.22	0.23	22.4	34.4	0.860	44.0
STD					0.15	0.17	0.08	8	0.04	0.04	0.5	7.4	0.014	1.8
COV					3	8	27	1	17	18	2	21	2	4
MIN	0.01	22.3	283		4.20	1.90	0.13	585	0.17	0.18	21.3	24.9	0.831	41.9
MAX	0.52	36.6	358		4.77	2.70	0.42	619	0.29	0.32	23.1	46.7	0.872	46.6

TABLE 6.2.9

Sulphate Emission Summary

SULPHATE EMISSION (g/bh-hr)
MODIFIED EPA HOT CYCLES ONLY

Fuel	Sulphur (%Wt)	Cummins NTCC400	% Total Part.	DDC Series 60	% Total Part
A	.15	.08	16	.07	33
B	.20	.13	24	.09	37
C	.01	.05	10	.04	22
D	.52	.12	20	.22	73
E	.40	.12	21	.12	45
F	.19	.09	20	.07	35

FUEL SULPHUR CONVERSION (%)
HOT CYCLES ONLY

Fuel	Sulphur (%Wt)	Cummins NTCC400	DDC Series 60
A	.15	2.9	2.9
B	.20	3.6	2.8
C	.01	*	*
D	.52	1.2	2.7
E	.40	1.6	2.0
F	.19	2.6	3.0

* Sulphate content too low on the particulate filter.

TABLE 6.3.1

ORTECH/VE-1 Emission Correlation
(gr/bhp-hr)
(CRC Fuel #7)

CUMMINS NTCC 400

Emission	ORTECH	VE-1	Ratio
NO_x	4.23	4.58	1.08
CO	2.66	2.32	.87
THC	.48	.57	1.19
Particulate	.49	.50	1.02

DDC SERIES 60

Emission	ORTECH	VE-1	Ratio
NO_x	4.53	4.67	1.03
CO	2.41	2.38	.99
THC	.35	.16	.46
Particulate	.21	.27	1.29

TABLE 6.3.2

WEIGHTED MODIFIED TRANSIENT EMISSION
CORRELATED TO CRC VE-1 PROGRAM
(GR/BHP-HR)

CUMMINS NTCC 400

Fuel	A	B	C	D	E	F	F	F
NO_x	4.58	4.86	4.45	4.95	4.74	4.77	4.96	4.75
CO	2.32	1.95	2.39	2.07	1.88	2.27	2.14	2.22
THC	.57	.50	.49	.55	.50	.58	.57	.60
PART.(UNCOR)	.50	.52	.49	.56	.55	.44	.41	.44

DDC SERIES 60

Fuel	A	B	C	D	E	F	F	F
NO_x	4.67	4.79	4.47	4.81	4.70	4.72	4.65	
CO	2.38	2.63	2.09	2.43	2.35	2.69	2.34	
THC	.16	.19	.07	.18	.14	.31	.23	
PART.(UNCOR)	.27	.36	.22	.39	.36	.30	.25	

Table 6.3.3
Emission Database NTCC 400
Corrected to CRC Data

Fuel #	% S	% Aro	90 DT	Test Date	NOX	CO 1.08	THC 1.19	CO2 1	UNC PART 1.02	COR PART 1.02	Work	Hum.	DenS.	Cetane #
F	0.19	25.5	283	01-Dec-88	4.31	2.78	0.60	690	0.44	0.49	27.4	25.2	0.831	41.9
F	0.19	25.5	283	01-Dec-88	4.38	2.76	0.60	685	0.43	0.48	27.3	25.2	0.831	41.9
F	0.19	25.5	283	01-Dec-88	4.44	2.72	0.57	657	0.42	0.47	27.6	25.2	0.831	41.9
F	0.19	25.5	283	01-Dec-88	4.48	2.65	0.58	669	0.43	0.47	27.2	25.2	0.831	41.9
F	0.19	25.5	283	01-Dec-88	4.52	2.70	0.58	674	0.42	0.47	27.2	25.7	0.831	41.9
F	0.19	25.5	283	01-Dec-88	4.56	2.62	0.58	678	0.42	0.47	27.2	28.6	0.831	41.9
C	0.01	22.3	336	04-Nov-88	4.09	2.92	0.48	644	0.47	0.50	28.2	48.3	0.865	46
C	0.01	22.3	336	04-Nov-88	4.21	2.92	0.46	648	0.49	0.51	28.1	56.7	0.865	46
C	0.01	22.3	336	04-Nov-88	4.29	2.99	0.43	636	0.48	0.49	28.1	61.5	0.865	46
C	0.01	22.3	336	04-Nov-88	4.10	3.01	0.50	649	0.47	0.49	28.1	62.7	0.865	46
C	0.01	22.3	336	04-Nov-88	4.11	2.97	0.49	657	0.47	0.49	28.2	54.4	0.865	46
C	0.01	22.3	336	04-Nov-88	4.14	3.01	0.49	620	0.48	0.49	28.1	58.5	0.865	46
A	0.15	28.4	317	10-Nov-88	4.21	3.02	0.57	645	0.51	0.52	27.1	60.6	0.851	46.6
A	0.15	28.4	317	10-Nov-88	4.25	2.94	0.58	662	0.49	0.51	27.0	54.2	0.851	46.6
A	0.15	28.4	317	10-Nov-88	4.26	2.81	0.56	666	0.48	0.51	27.1	47.3	0.851	46.6
A	0.15	28.4	317	10-Nov-88	4.26	2.79	0.56	661	0.48	0.51	27.2	40.5	0.851	46.6
A	0.15	28.4	317	10-Nov-88	4.32	2.71	0.56	646	0.47	0.50	27.2	37.6	0.851	46.6
B	0.20	36.6	329	17-Nov-88	4.78	2.43	0.49	689	0.50	0.52	27.1	52.8	0.872	43.9
B	0.20	36.6	329	17-Nov-88	4.52	2.41	0.48	670	0.51	0.57	27.2	25.4	0.872	43.9
B	0.20	36.6	329	17-Nov-88	4.48	2.43	0.49	675	0.52	0.58	27.1	23.5	0.872	43.9
B	0.20	36.6	329	17-Nov-88	4.58	2.40	0.49	676	0.52	0.57	27.0	25.4	0.872	43.9
B	0.20	36.6	329	17-Nov-88	4.55	2.35	0.49	672	0.51	0.56	27.2	23.9	0.872	43.9
B	0.20	36.6	329	17-Nov-88	4.57	2.35	0.49	675	0.51	0.57	27.1	23.9	0.872	43.9
D	0.52	34.7	349	24-Nov-88	4.66	2.61	0.52	695	0.55	0.60	27.5	28.8	0.863	41.9
D	0.52	34.7	349	24-Nov-88	4.60	2.52	0.51	697	0.54	0.60	27.4	27.3	0.863	41.9
D	0.52	34.7	349	24-Nov-88	4.65	2.42	0.55	683	0.56	0.62	27.5	27.3	0.863	41.9
D	0.52	34.7	349	24-Nov-88	4.67	2.43	0.52	695	0.54	0.59	27.5	29.4	0.863	41.9
D	0.52	34.7	349	24-Nov-88	4.63	2.47	0.52	685	0.56	0.62	27.5	29.4	0.863	41.9
D	0.52	34.7	349	24-Nov-88	4.57	2.49	0.52	689	0.55	0.60	27.5	28.6	0.863	41.9
E	0.40	30.1	358	08-Dec-88	4.55	2.32	0.46	701	0.52	0.58	27.7	27.7	0.863	43.9
E	0.40	30.1	358	08-Dec-88	4.44	2.32	0.46	681	0.55	0.61	24.0	27.7	0.863	43.9
E	0.40	30.1	358	08-Dec-88	4.39	2.28	0.49	690	0.53	0.59	20.8	27.9	0.863	43.9
E	0.40	30.1	358	08-Dec-88	4.42	2.21	0.49	693	0.52	0.58	20.6	27.8	0.863	43.9
E	0.40	30.1	358	08-Dec-88	4.37	2.24	0.49	697	0.53	0.59	20.5	28.0	0.863	43.9
E	0.40	30.1	358	08-Dec-88	4.41	2.19	0.48	694	0.52	0.58	20.5	27.8	0.863	43.9
AVG					4.42	2.59	0.50	672	0.51	0.55	26.4	37.8	0.863	44.4
STD					0.19	0.28	0.04	21	0.03	0.04	2.4	13.8	0.006	1.7
COV					4	11	7	3	5	8	9	36	1	4
MIN	0.01	22.3	317		4.09	2.192	0.428	620	0.467	0.485	20.5	23.5	0.8511	41.9
MAX	0.52	36.6	358		4.78	3.024	0.583	701	0.558	0.615	28.2	62.7	0.8717	46.6

Table 6.3.4
Emission Database DDC 6R544
Corrected to CRC Data

Fuel #	% S	% Aro	90 PT	Test Date	NOX 1.03	CO 0.99	THC 0.46	CO2 1.00	UNC PART 1.29	COR PART 1.29	Work	Hum.	Den	Cetane #
F	0.19	25.5	283	20-Sep-88	4.58	2.48	0.23	609	0.26	0.26	21.0	82.1	0.8309	41.9
F	0.19	25.5	283	20-Sep-88	4.69	2.42	0.23	583	0.25	0.25	21.2	77.2	0.8309	41.9
F	0.19	25.5	283	20-Sep-88	4.82	2.45	0.22	583	0.28	0.28	21.2	77.1	0.8309	41.9
F	0.19	25.5	283	20-Sep-88	4.83	2.41	0.21	598	0.26	0.26	21.2	77.1	0.8309	41.9
F	0.19	25.5	283	20-Sep-88	4.92	2.35	0.19	604	0.27	0.27	21.3	87.3	0.8309	41.9
F	0.19	25.5	283	20-Sep-88	4.93	2.36	0.19	602	0.26	0.27	21.3	88.9	0.8309	41.9
A	0.15	28.4	317	15-Oct-88	4.64	2.19	0.14	603	0.25	0.28	21.9	44.3	0.8511	46.6
A	0.15	28.4	317	15-Oct-88	4.65	2.19	0.14	604	0.25	0.27	21.9	42.2	0.8511	46.6
A	0.15	28.4	317	15-Oct-88	4.61	2.19	0.13	602	0.26	0.28	21.9	43.5	0.8511	46.6
A	0.15	28.4	317	15-Oct-88	4.59	2.20	0.14	607	0.25	0.26	21.8	45.8	0.8511	46.6
A	0.15	28.4	317	15-Oct-88	4.62	2.24	0.14	604	0.26	0.27	21.7	46.7	0.8511	46.6
B	0.20	36.6	329	08-Nov-88	4.83	2.21	0.16	619	0.29	0.31	22.7	44.8	0.8717	43.9
B	0.20	36.6	329	08-Nov-88	4.76	2.67	0.14	600	0.29	0.31	22.7	42.5	0.8717	43.9
B	0.20	36.6	329	08-Nov-88	4.77	2.44	0.14	596	0.28	0.30	22.7	44.8	0.8717	43.9
B	0.20	36.6	329	08-Nov-88	4.73	2.45	0.14	591	0.29	0.31	22.6	41.8	0.8717	43.9
B	0.20	36.6	329	08-Nov-88	4.71	2.57	0.14	611	0.31	0.33	22.8	42.7	0.8717	43.9
B	0.20	36.6	329	08-Nov-88	4.73	2.50	0.14	589	0.29	0.31	23.1	43.8	0.8717	43.9
C	0.01	22.3	336	15-Nov-88	4.47	2.05	0.06	597	0.22	0.24	22.7	34.9	0.8649	46.0
C	0.01	22.3	336	15-Nov-88	4.33	1.88	0.07	585	0.22	0.24	22.7	29.3	0.8649	46.0
C	0.01	22.3	336	15-Nov-88	4.42	1.95	0.07	585	0.22	0.24	22.8	33.6	0.8649	46.0
C	0.01	22.3	336	15-Nov-88	4.44	1.92	0.07	590	0.22	0.24	22.7	32.2	0.8649	46.0
C	0.01	22.3	336	15-Nov-88	4.44	1.96	0.06	589	0.22	0.24	22.7	35.6	0.8649	46.0
C	0.01	22.3	336	15-Nov-88	4.42	2.00	0.07	591	0.22	0.24	22.7	36.1	0.8649	46.0
D	0.52	34.7	349	22-Nov-88	4.88	2.23	0.15	605	0.35	0.39	22.6	27.2	0.8707	41.9
D	0.52	34.7	349	22-Nov-88	4.89	2.16	0.13	601	0.35	0.38	22.7	27.3	0.8707	41.9
D	0.52	34.7	349	22-Nov-88	4.84	2.19	0.14	606	0.35	0.38	22.7	26.3	0.8707	41.9
D	0.52	34.7	349	22-Nov-88	4.86	2.18	0.13	595	0.34	0.38	22.7	26.4	0.8707	41.9
D	0.52	34.7	349	22-Nov-88	4.89	2.21	0.14	596	0.35	0.39	22.8	28.4	0.8707	41.9
D	0.52	34.7	349	22-Nov-88	4.91	2.20	0.15	600	0.37	0.41	22.7	28.4	0.8707	41.9
F	0.19	25.5	283	29-Nov-88	4.61	2.22	0.18	592	0.23	0.26	21.4	25.6	0.8309	41.9
F	0.19	25.5	283	29-Nov-88	4.67	2.28	0.19	598	0.23	0.25	21.3	25.6	0.8309	41.9
F	0.19	25.5	283	29-Nov-88	4.69	2.22	0.18	594	0.23	0.26	21.4	26.8	0.8309	41.9
F	0.19	25.5	283	29-Nov-88	4.62	2.19	0.18	596	0.23	0.25	21.5	24.9	0.8309	41.9
F	0.19	25.5	283	29-Nov-88	4.64	2.15	0.18	587	0.24	0.27	21.5	25.0	0.8309	41.9
E	0.40	30.1	358	06-Dec-88	4.70	2.18	0.12	602	0.31	0.34	22.7	32.9	0.8625	43.9
E	0.40	30.1	358	06-Dec-88	4.64	2.17	0.12	603	0.30	0.33	22.8	32.9	0.8625	43.9
E	0.40	30.1	358	06-Dec-88	4.68	2.15	0.11	596	0.31	0.34	22.7	31.6	0.8625	43.9
E	0.40	30.1	358	06-Dec-88	4.56	2.15	0.13	602	0.32	0.35	22.8	29.0	0.8625	43.9
E	0.40	30.1	358	06-Dec-88	4.66	2.18	0.12	601	0.32	0.35	22.7	33.1	0.8625	43.9
AVG					4.66	2.20	0.13	598	0.28	0.30	22.4	34.4	0.860	44.0
STD					0.15	0.17	0.04	8	0.05	0.05	0.5	7.4	0.014	1.8
COV					3	8	27	1	17	18	2	21	2	4
MIN	0.01	22.3	283		4.33	1.88	0.06	585	0.216	0.236	21.3	24.9	0.831	41.9
MAX	0.52	36.6	358		4.91	2.67	0.19	619	0.374	0.411	23.1	46.7	0.872	46.6

TABLE 6.4.1

ARB REGRESSION ANALYSIS USING VE-1 DATA

Emission = A + B * Aromatics (% Vol.)
+ C * Sulphur (% WT)

CUMMINS NTCC 400

	A	B	C
PMCC	.44	5.4×10^{-3}	0
PMHC	.37	3.9×10^{-3}	0
NO_XCC	3.9	11.9×10^{-3}	0
NO_XHC	4.3	12.8×10^{-3}	0

DDC SERIES 60

PMCC	.21	$.22 \times 10^{-3}$	1.5
PMHC	.18	$.097 \times 10^{-3}$	.32
NO_XCC	3.99	30×10^{-3}	0
NO_XHC	3.85	28×10^{-3}	0

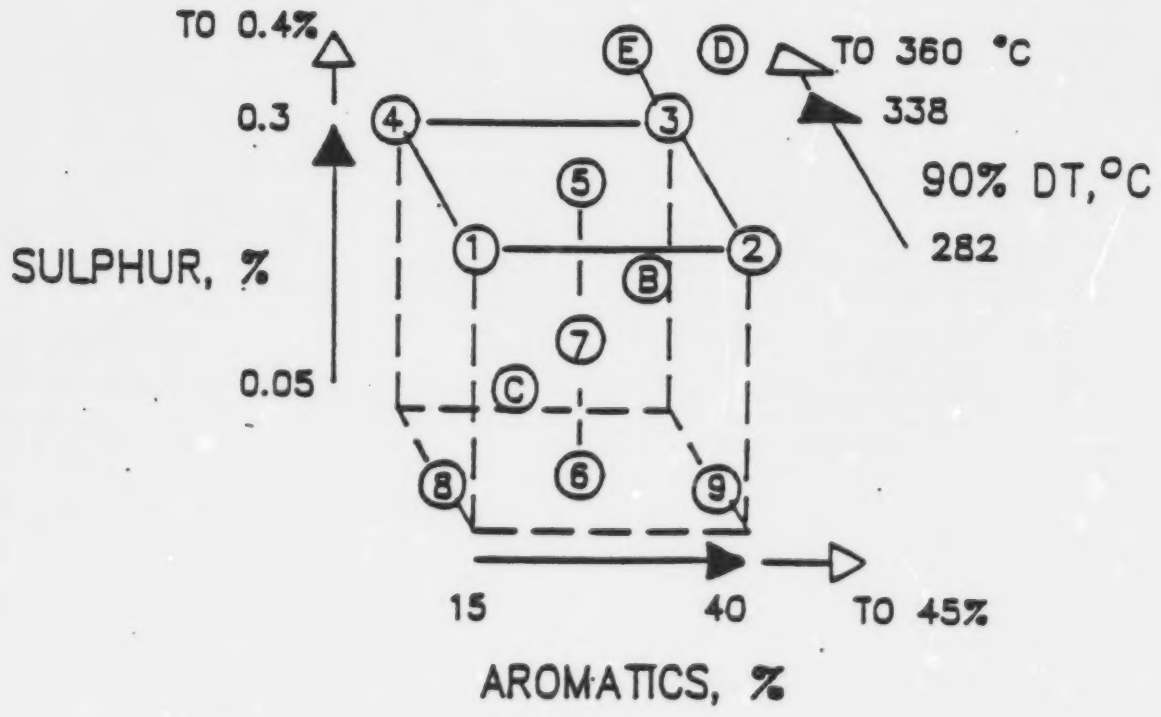
* CC - cold cycles
HC - hot cycles

* where C = 0 sulphur content is not statistically significant.

FIGURE 6.1.1

CRC VE-1 & CANADIAN FUEL MATRIX

ROPERTIES	U.S. CRC VE-1 MATRIX BOUNDARIES	CANADIAN PACE MATRIX ADDITIONS
0% DISTILLATION TEMP.	540 - 640°F	540 - 680°F (360 C)
MASS SULPHUR	0.05 - 0.30	0.05 - 0.40
: AROMATICS	15 - 40	15 - 45
	1 → 9	B → E



Emission Impact
Diesel Fuel Quality

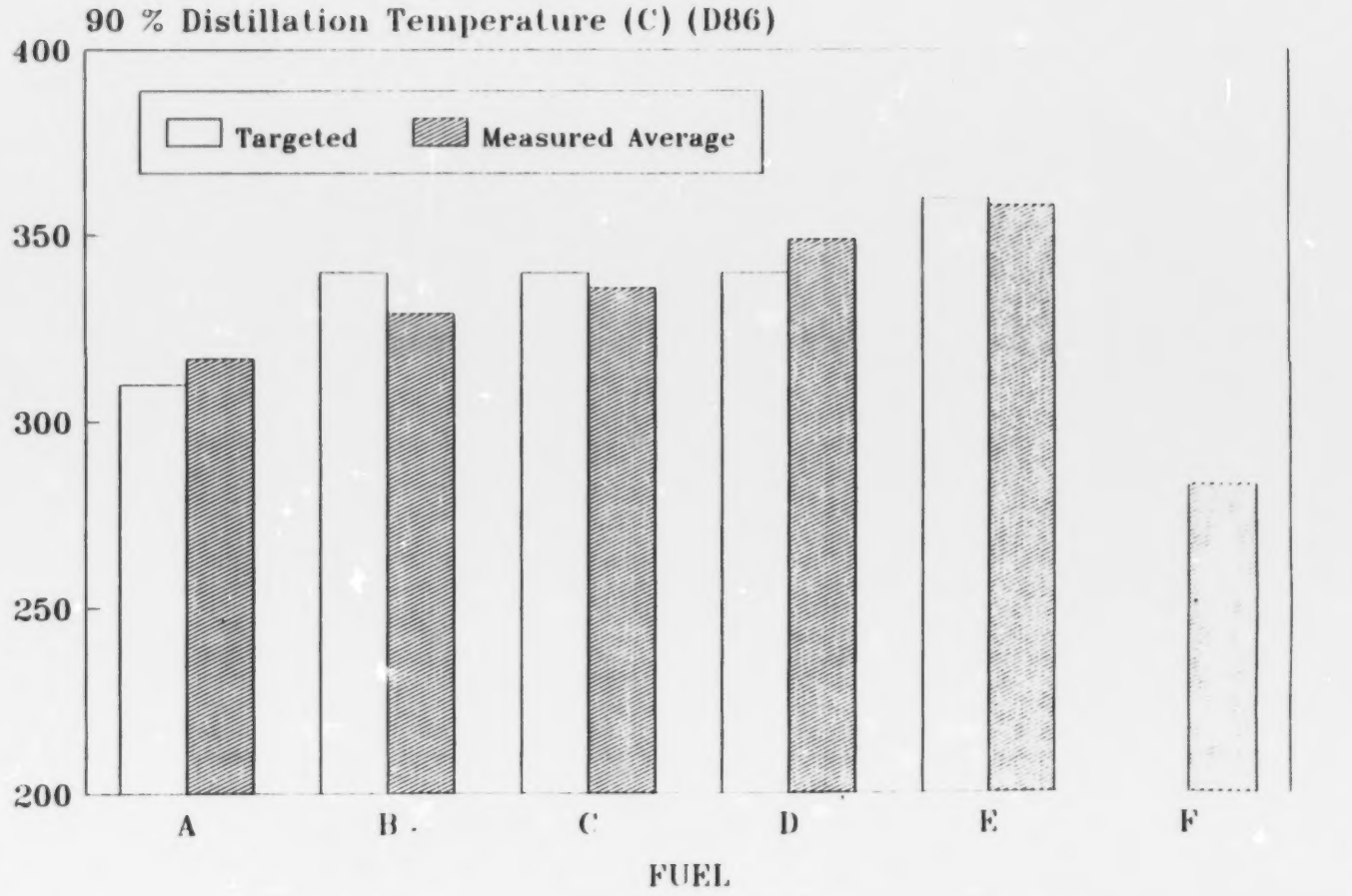


Figure 6.1.2

AETC - ORTECH International

Emission Impact
Diesel Fuel Quality

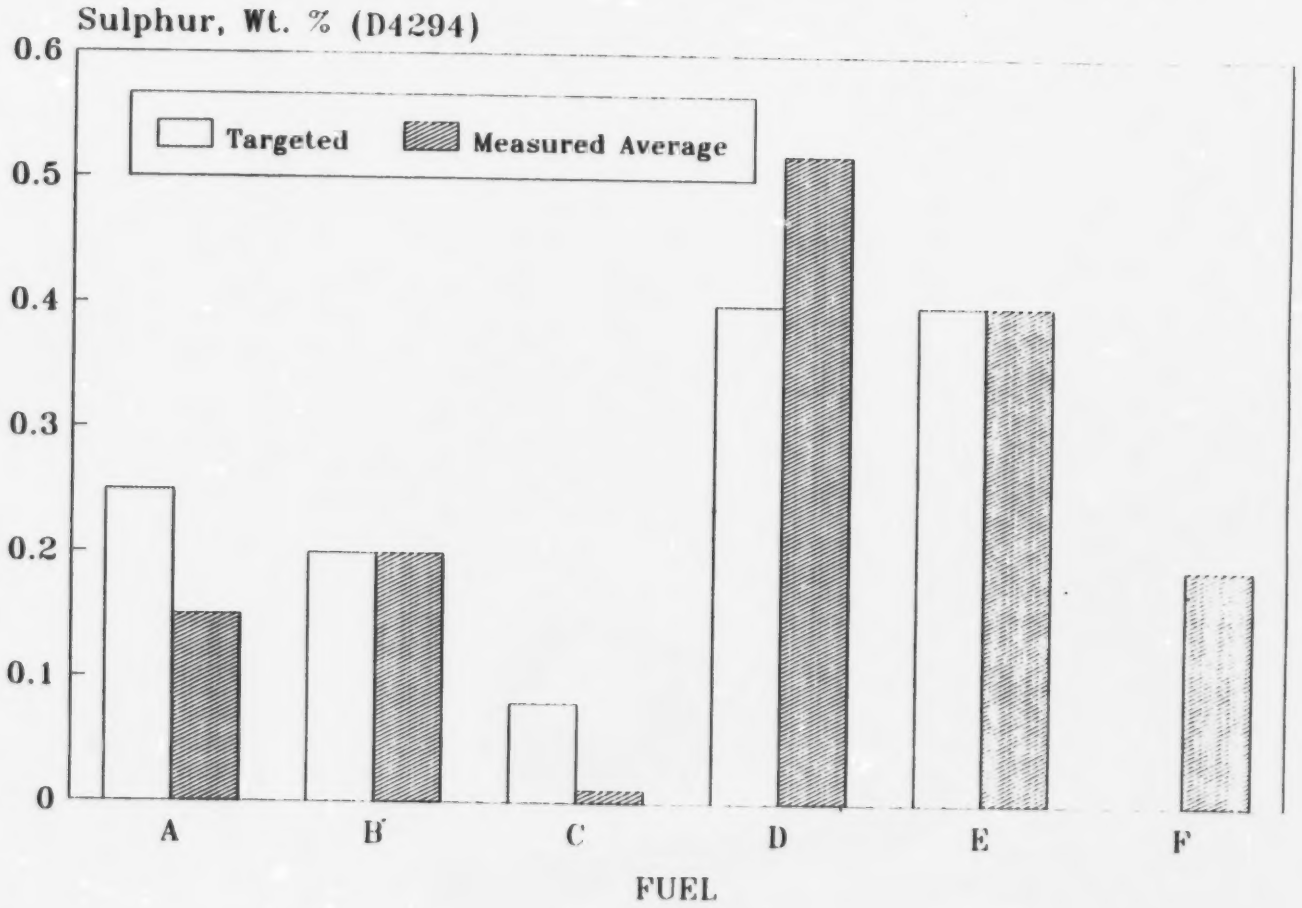


Figure 6.1.3

AETC–ORTECH International

Emission Impact
Diesel Fuel Quality

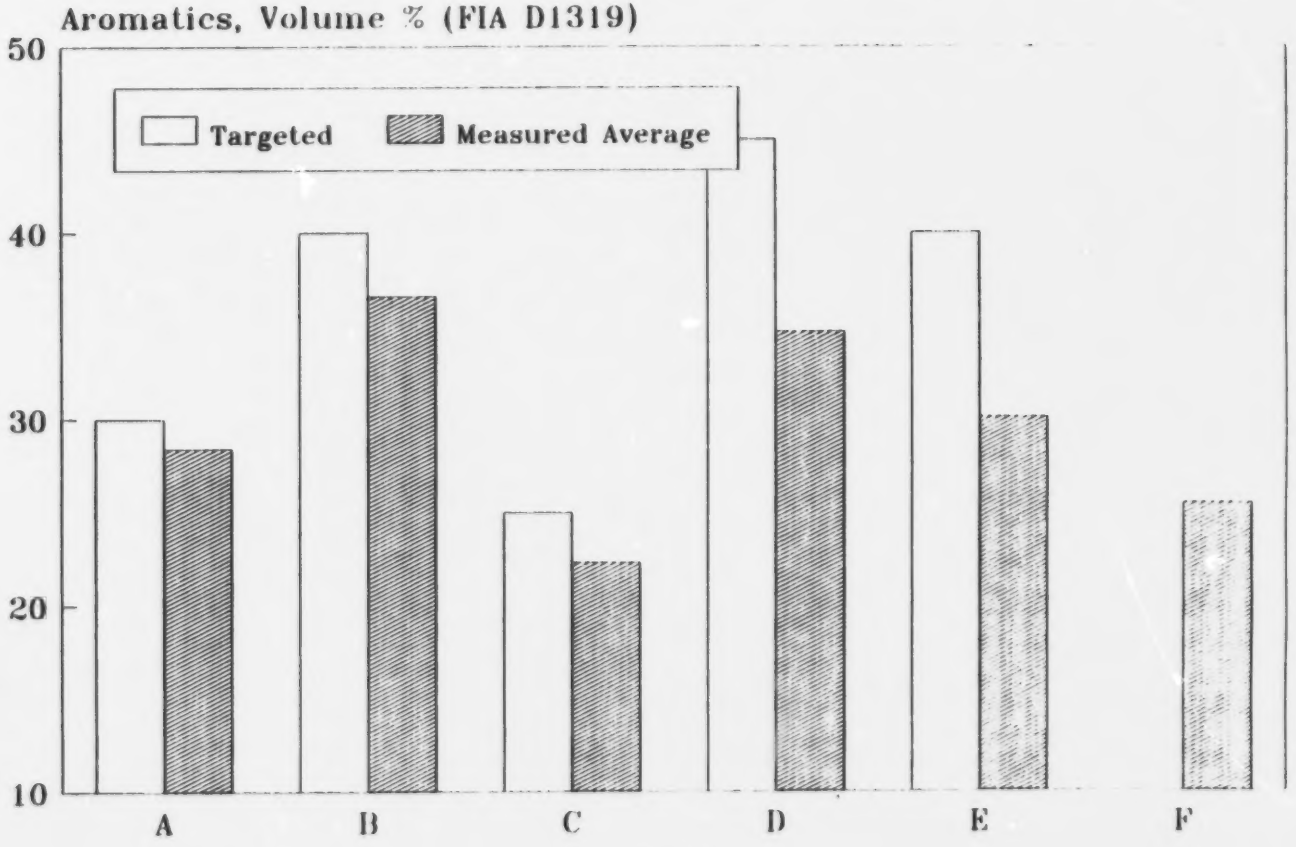


Figure 6.1.4

AETC-ORTECH International

Emission Impact
Diesel Fuel Quality(NTCC 400)
Modified EPA Transient Cycles Emission

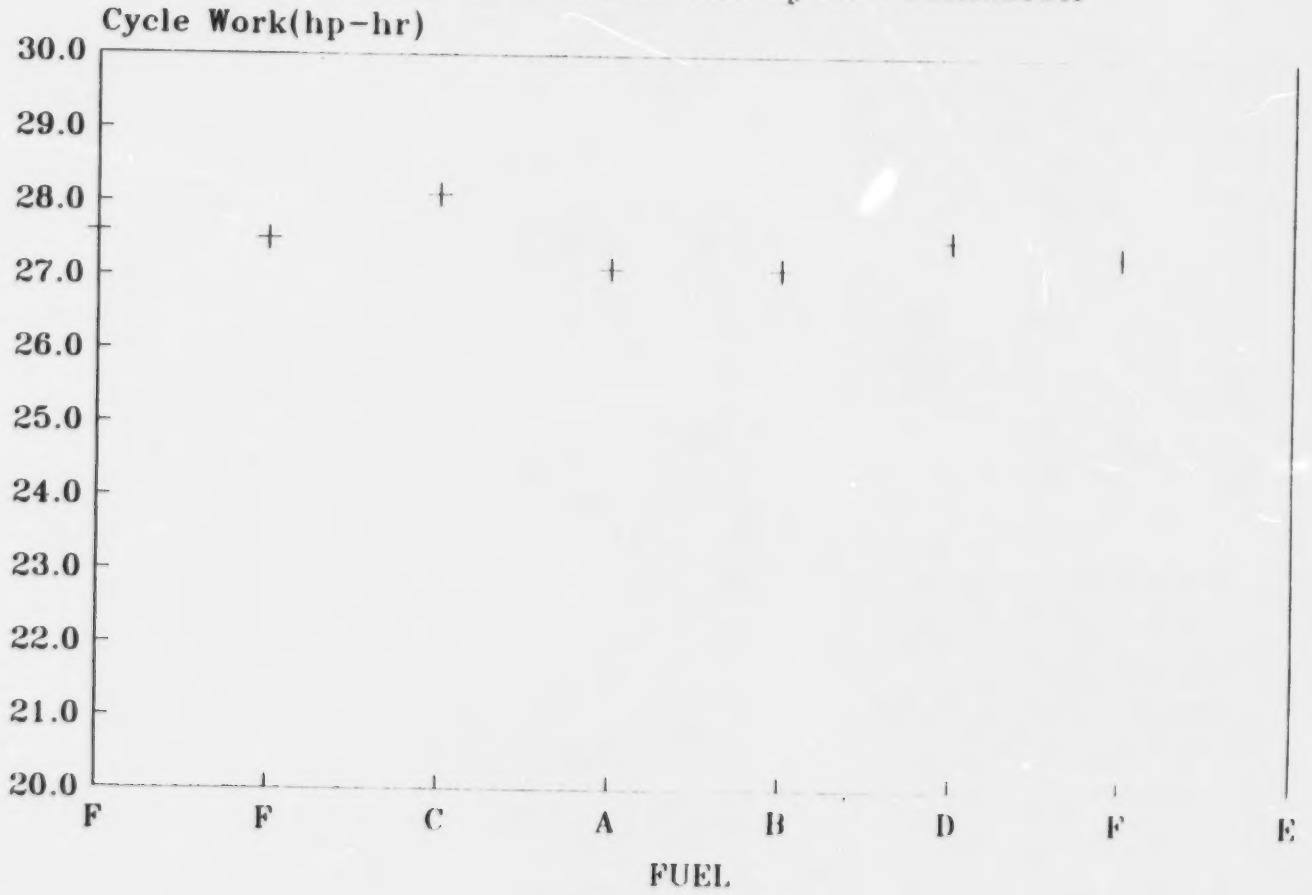


Figure 6.2.1

AET-ORTECH International

Emission Impact
Diesel Fuel Quality(NTCC 400)
Modified EPA Transient Cycles Emission

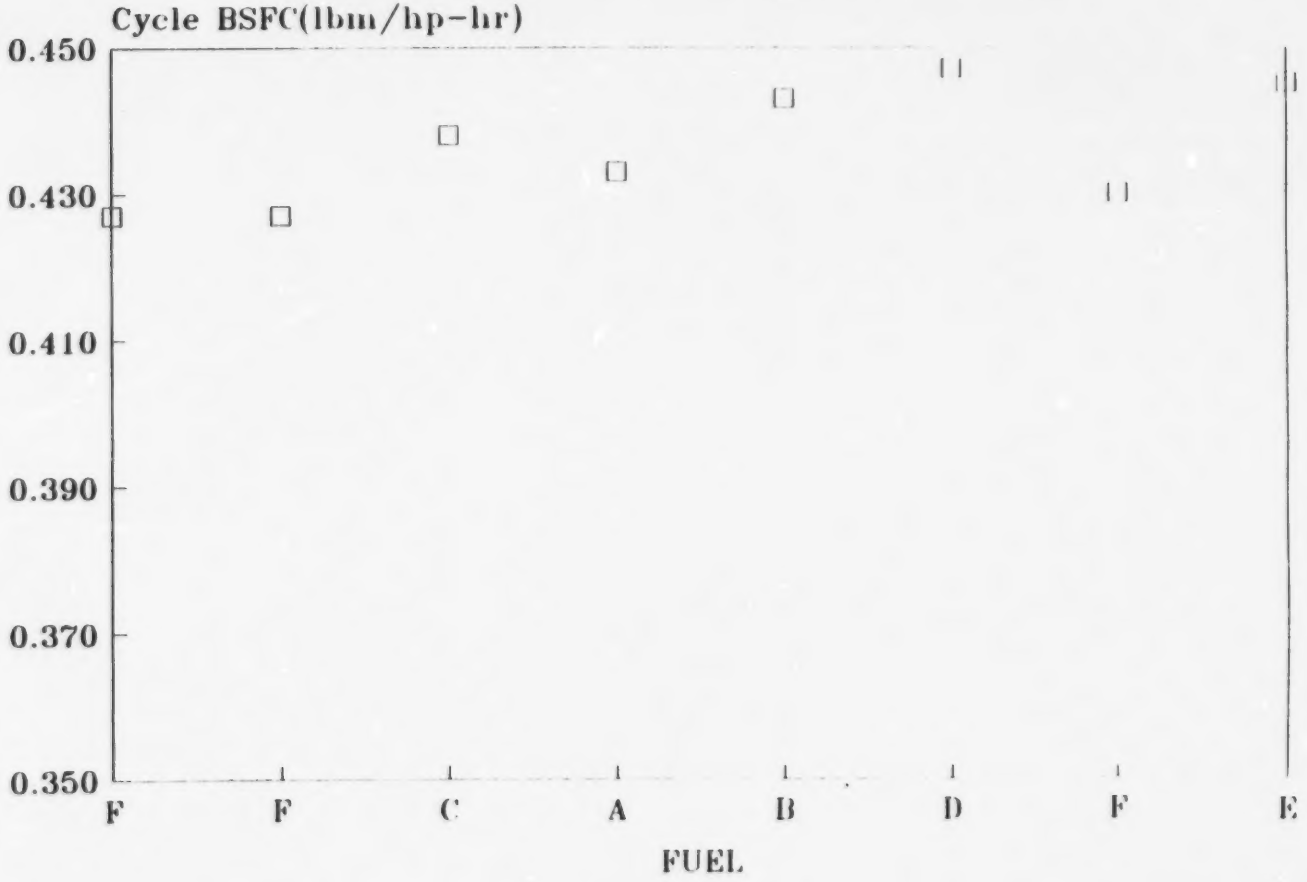


Figure 6.2.2

Emission Impact
Diesel Fuel Quality(DDC 6R5-11)
Modified EPA Transient Cycles Emission

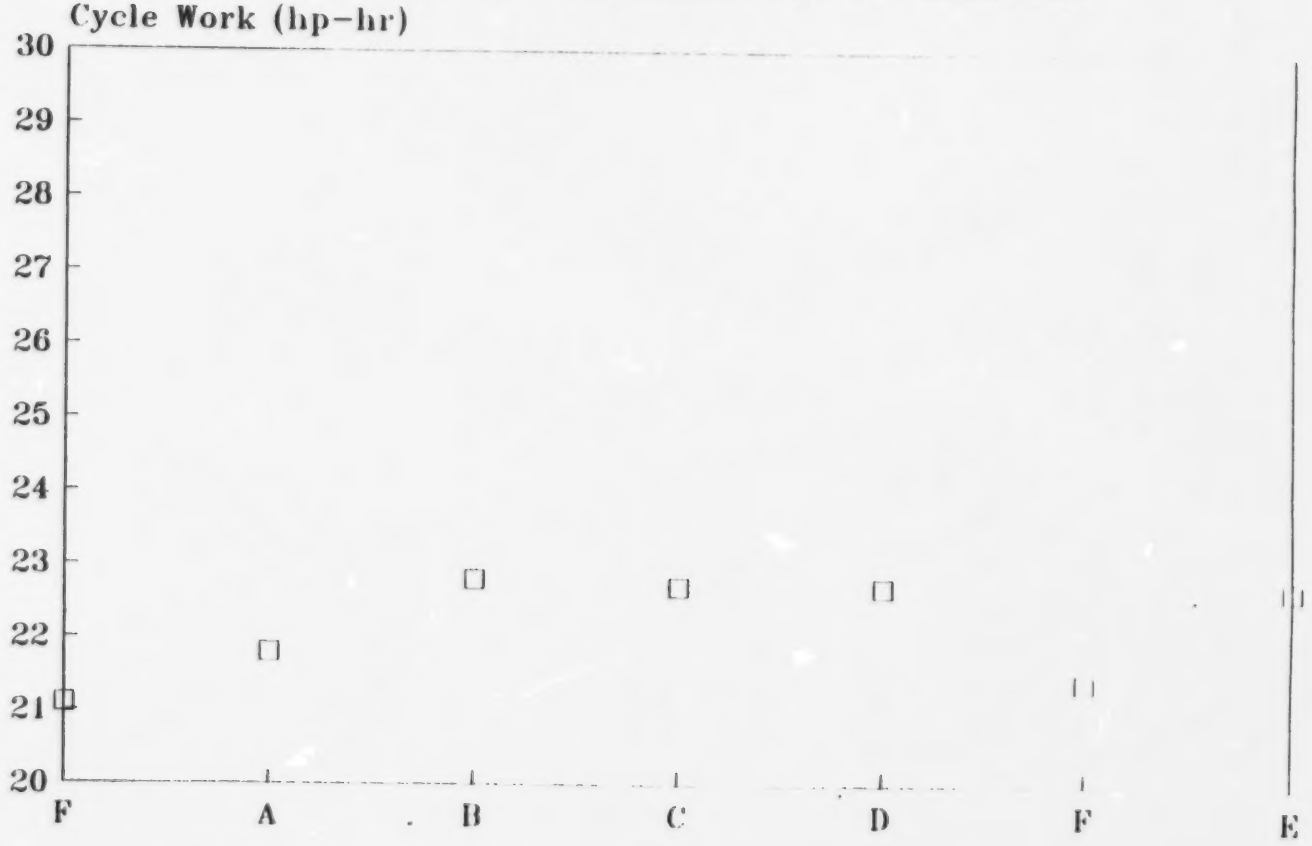


Figure 6.2.3

AET-ORTECH International

Emission Impact
Diesel Fuel Quality(DDC 6R541)
Modified EPA Transient Cycles Emission

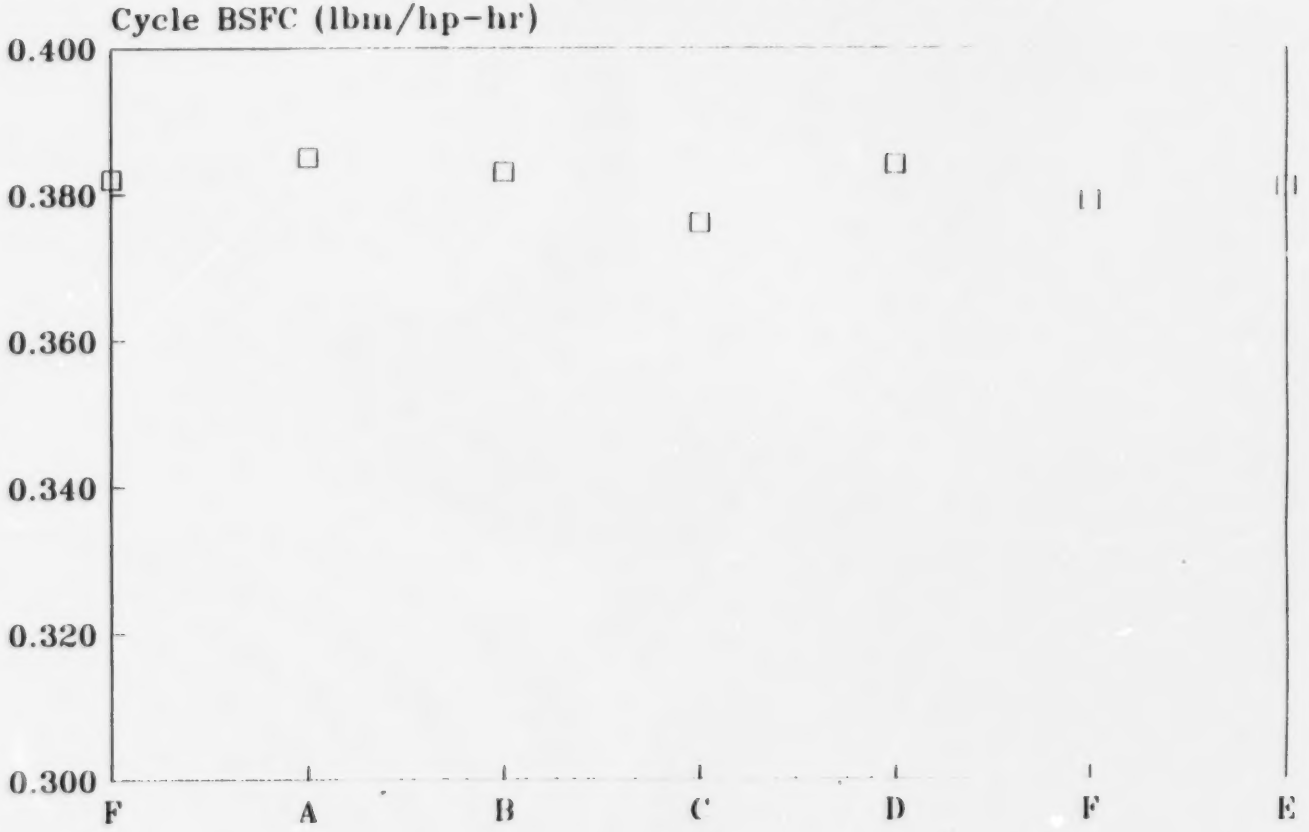


Figure 6.2.4

AET-ORTECH International

Emission Impact (Diesel Fuel Quality)

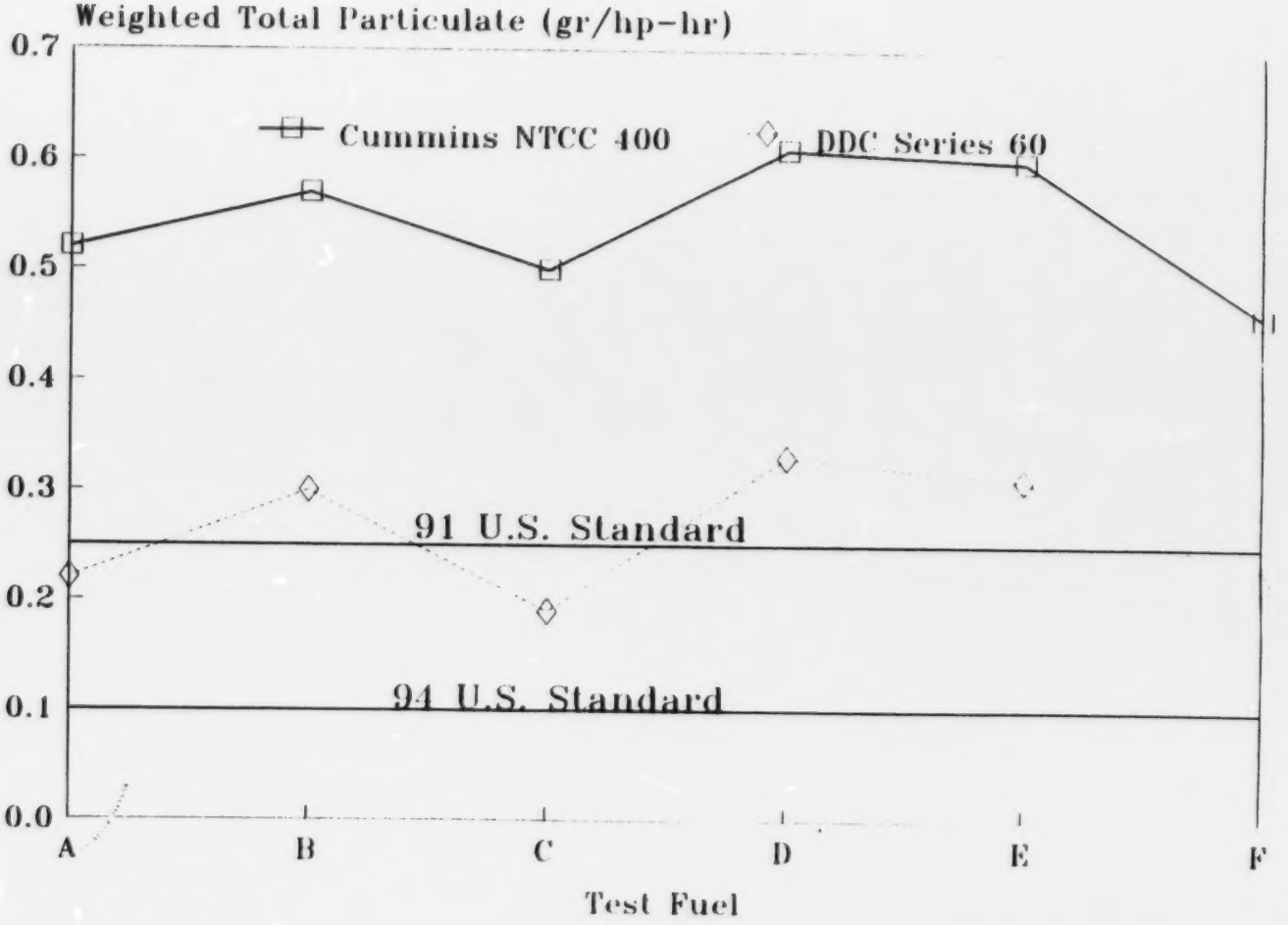


Figure 6.2.5

AET-ORTECH International

Emission Impact (Diesel Fuel Quality)

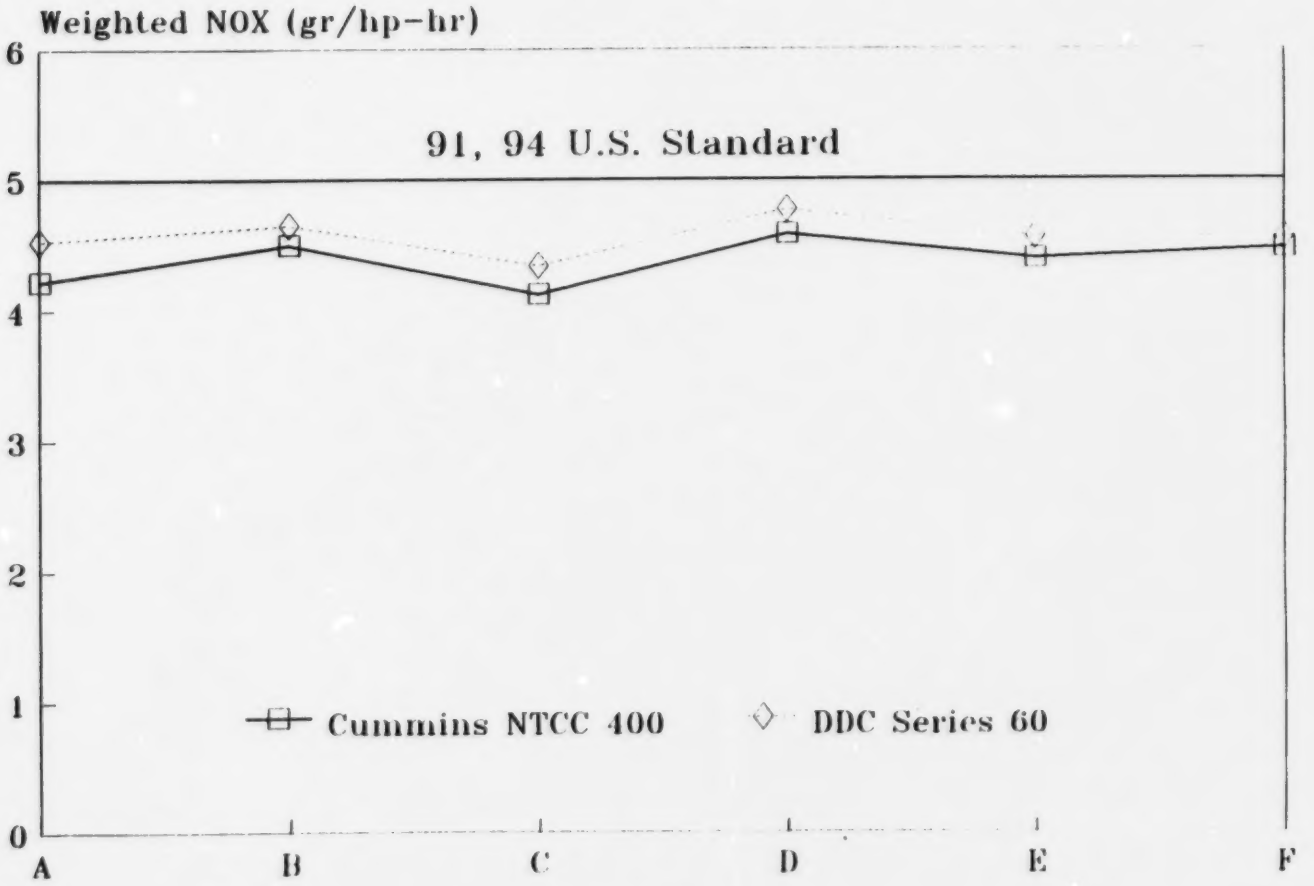


Figure 6.2.6

AET-ORTECH International

Emission Impact (Diesel Fuel Quality)

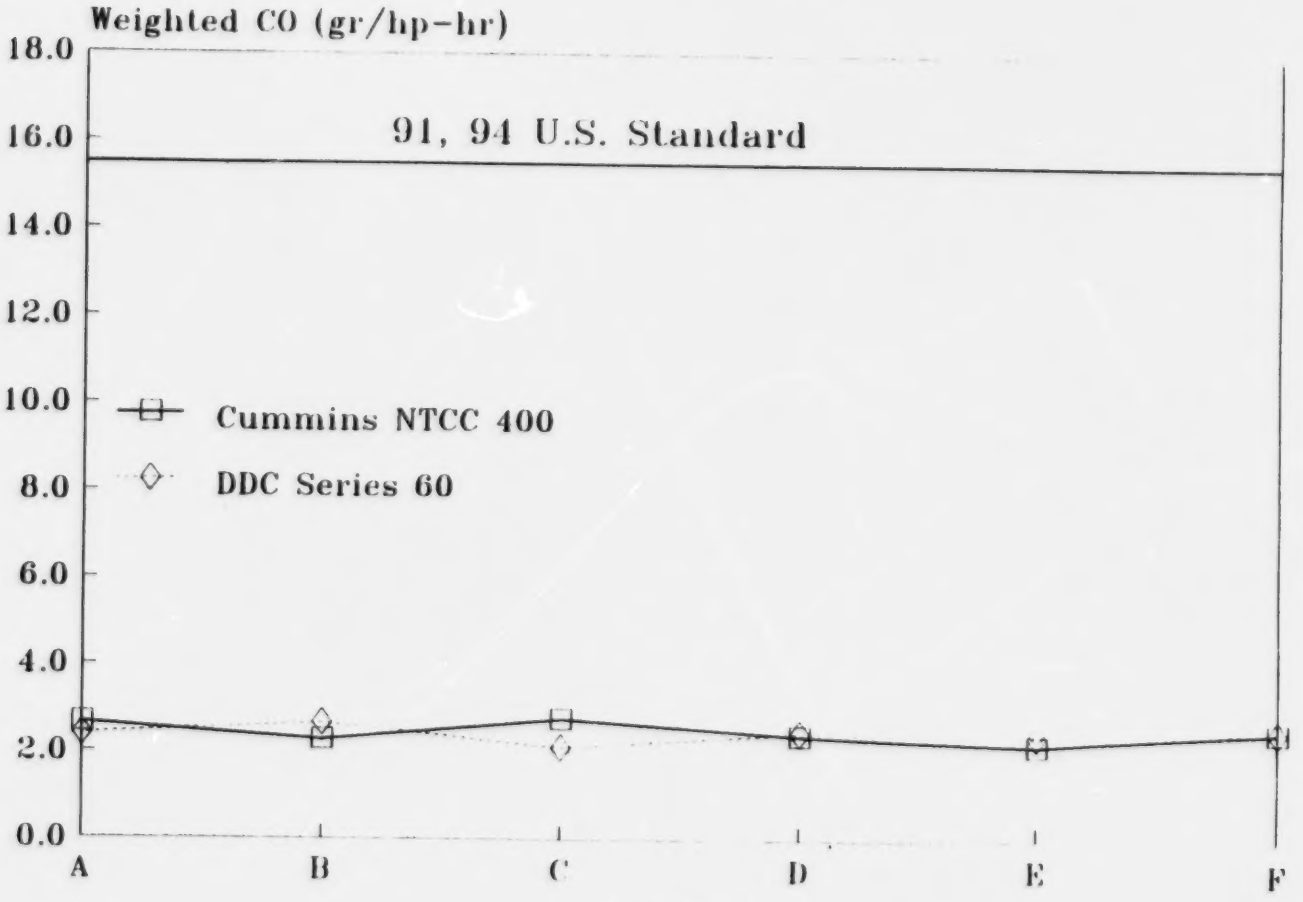


Figure 6.2.7

AET-ORTECH International

Emission Impact (Diesel Fuel Quality)

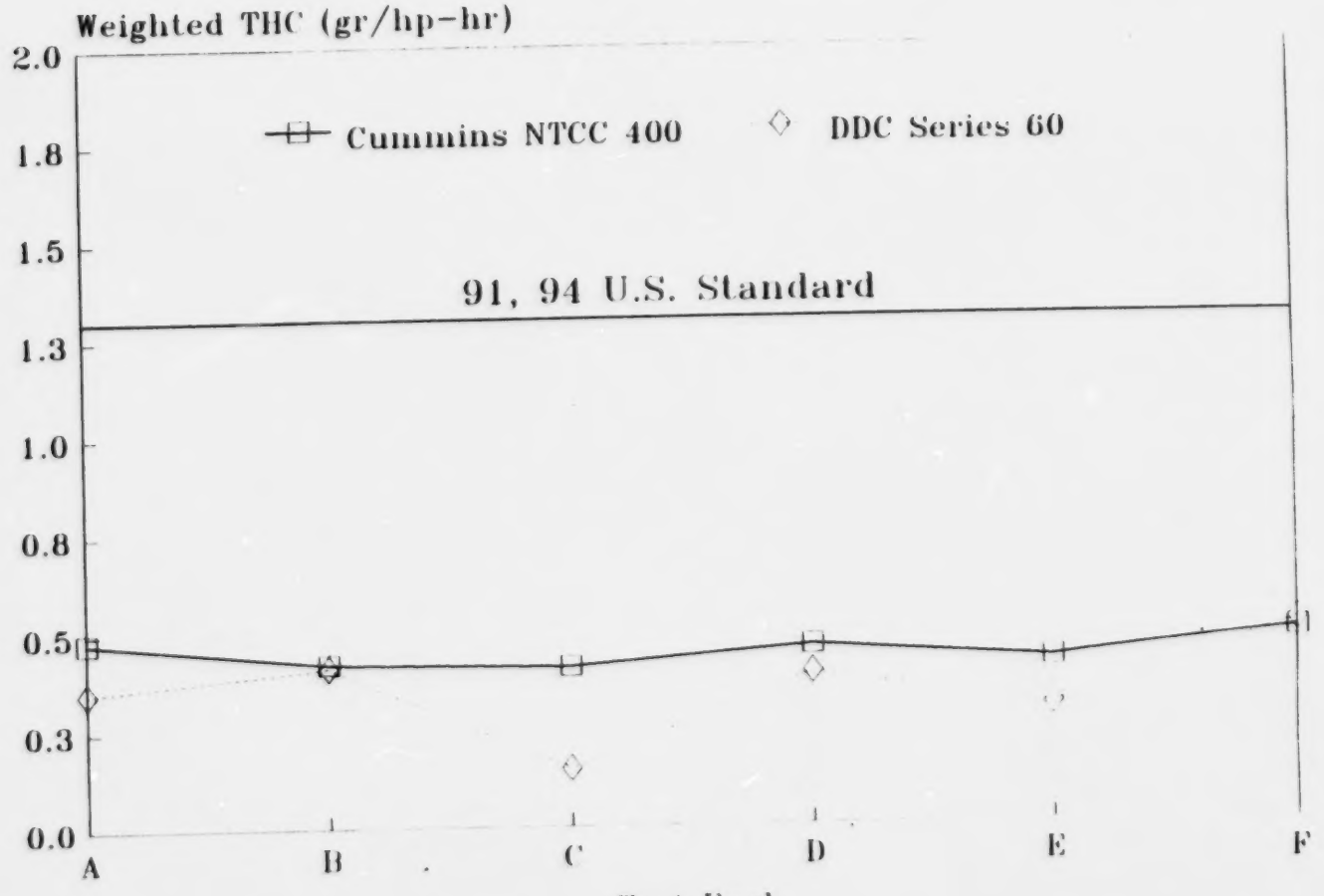


Figure 6.2.8

AET-ORTECH International

Emission Impact
Diesel Fuel Quality

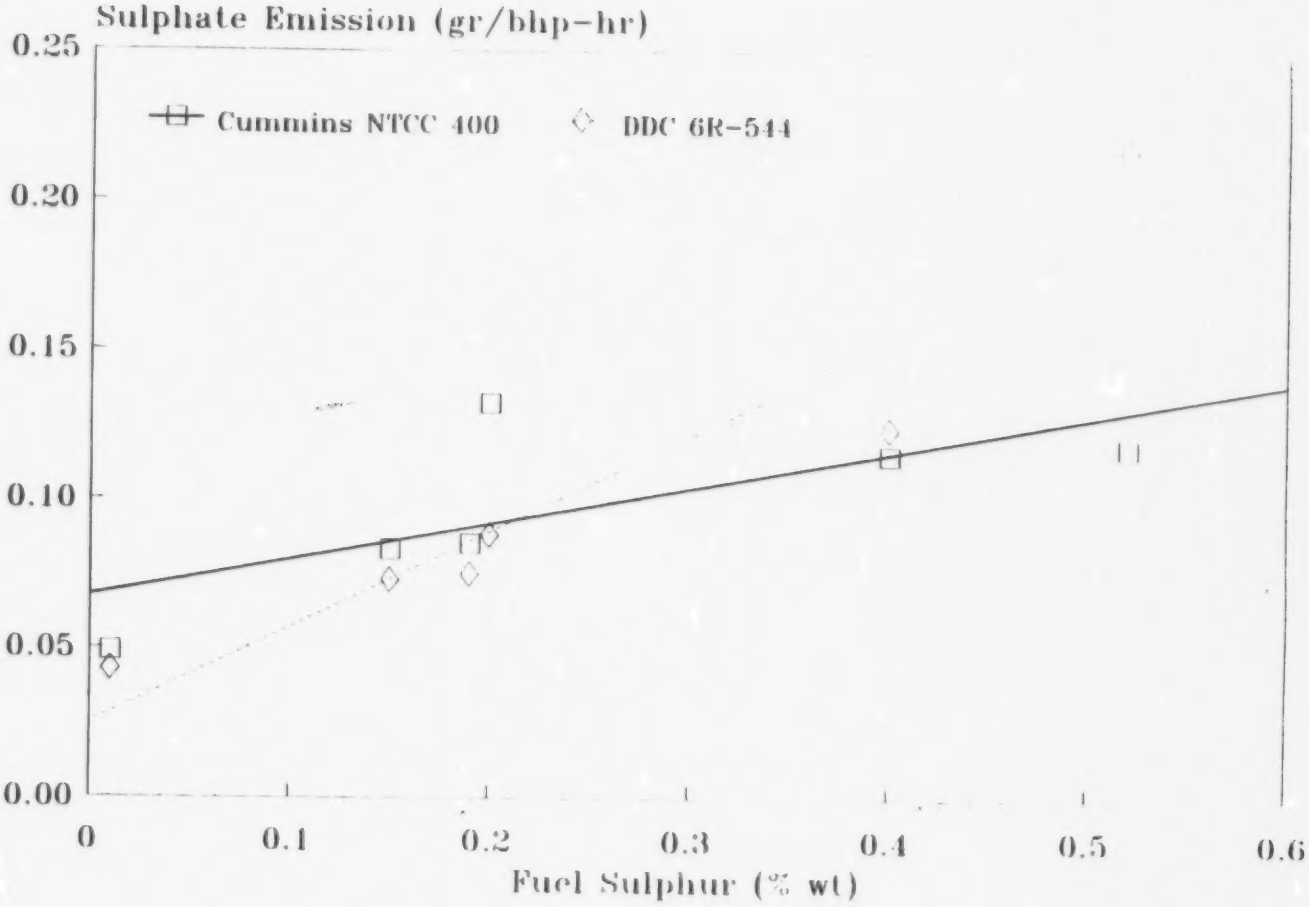


Figure 6.2.9

AETC-ORTECH International

Emission Impact
Diesel Fuel Quality

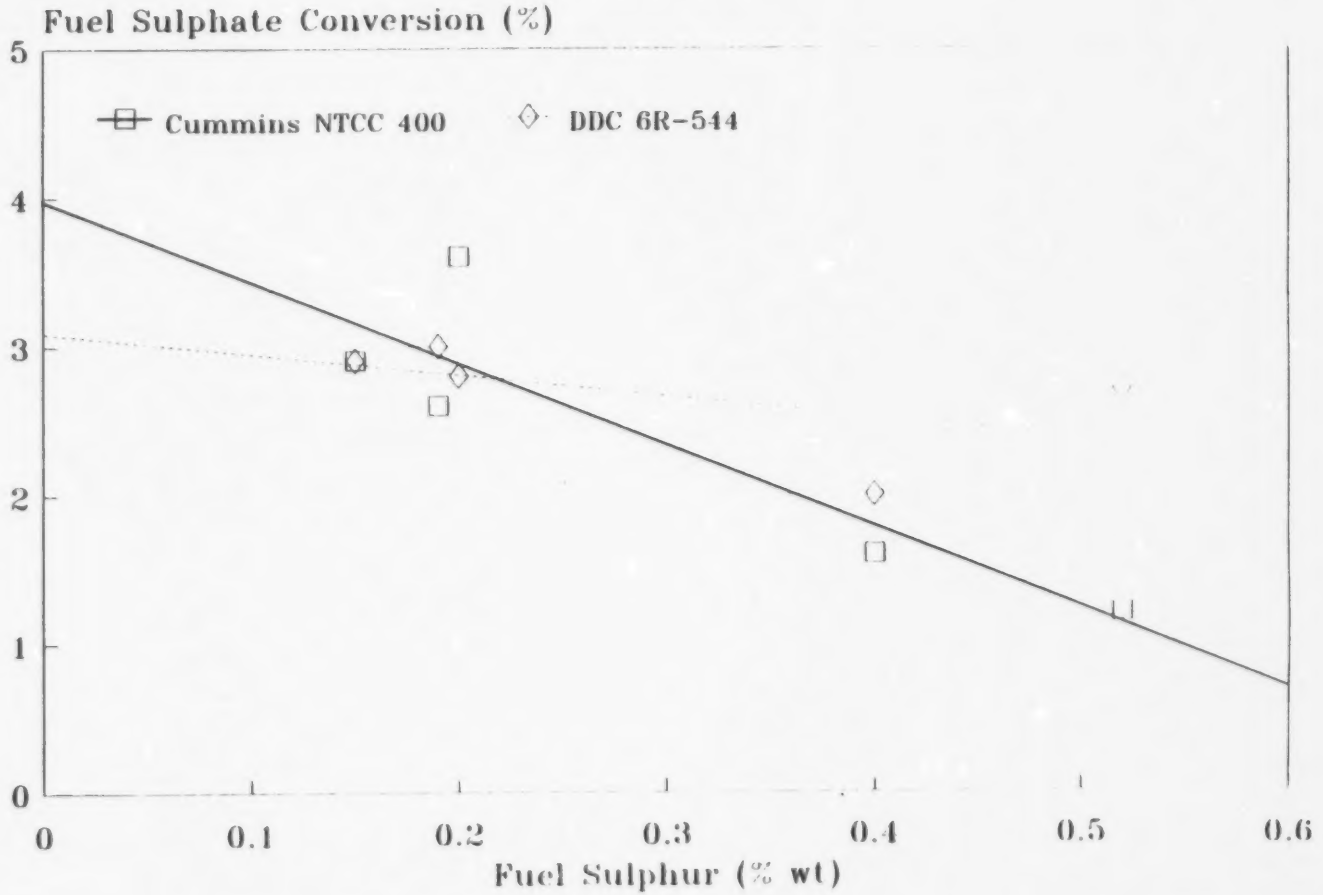


Figure 6.2.10

AETC-ORTECH International

Emission Impact
Diesel Fuel Quality

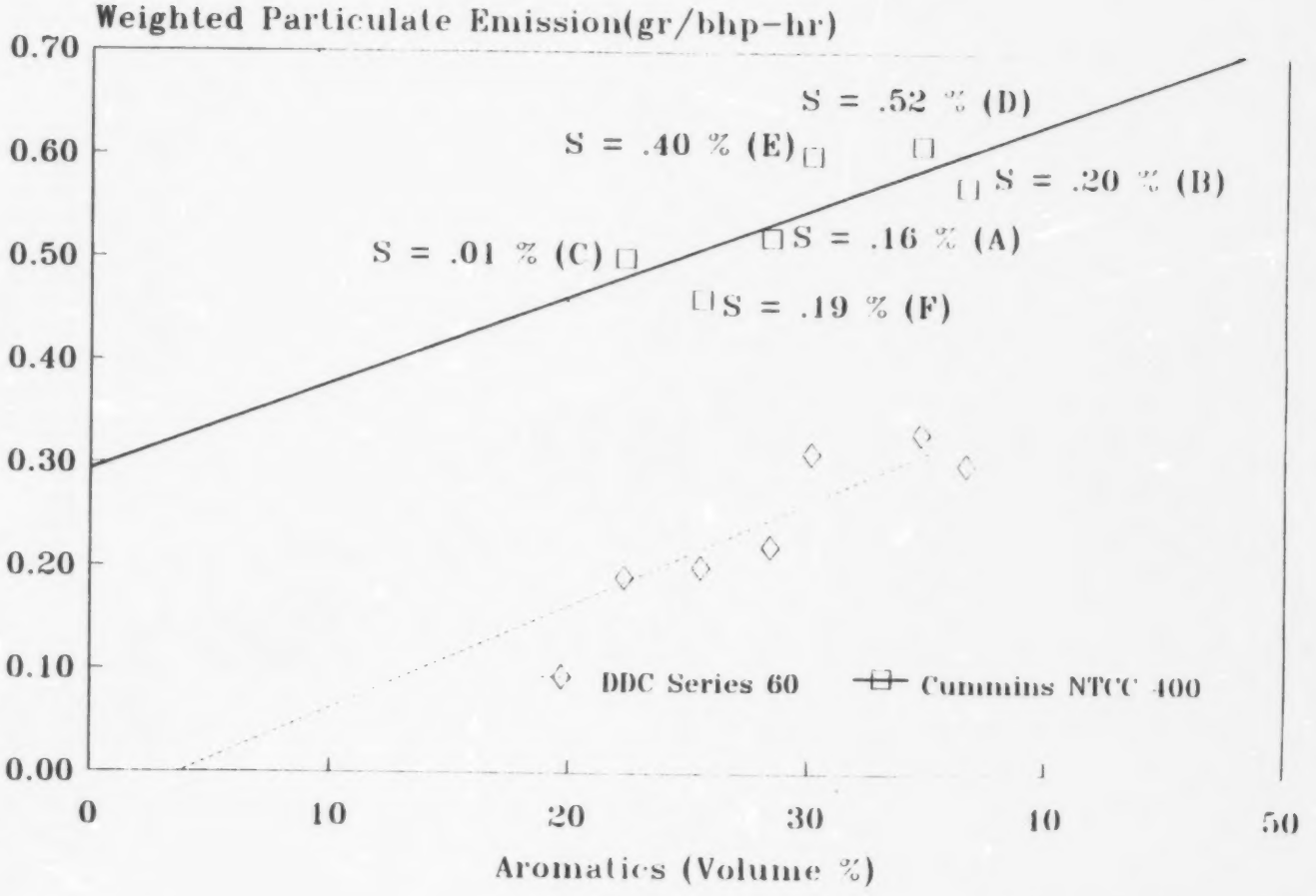


Figure 6.4.1

AET-ORTECH International

Emission Impact
Diesel Fuel Quality

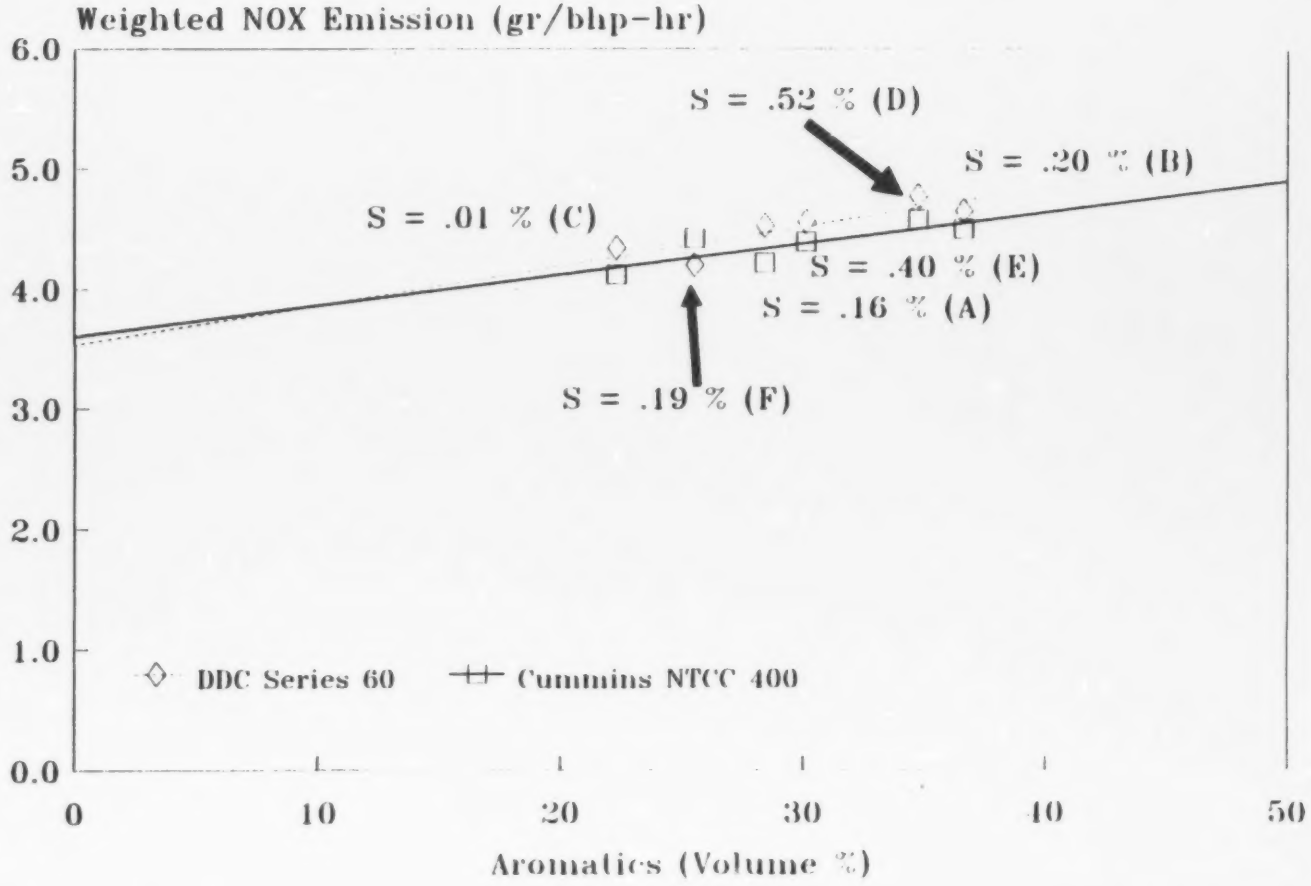


Figure 6.4.2

AET-ORTECH International

Emission Impact
Diesel Fuel Quality

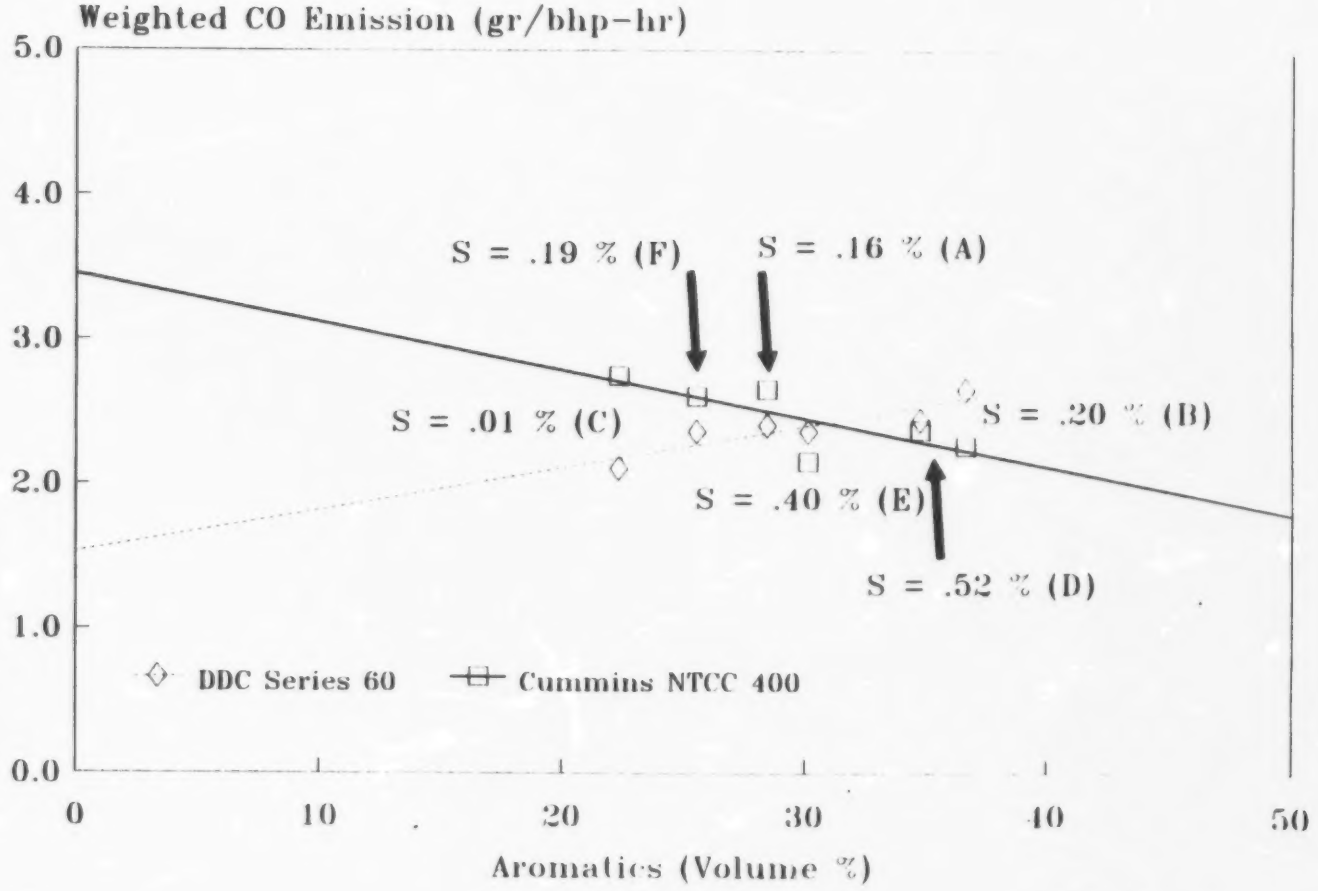


Figure 6.4.3

AET-ORTECH International

Emission Impact
Diesel Fuel Quality

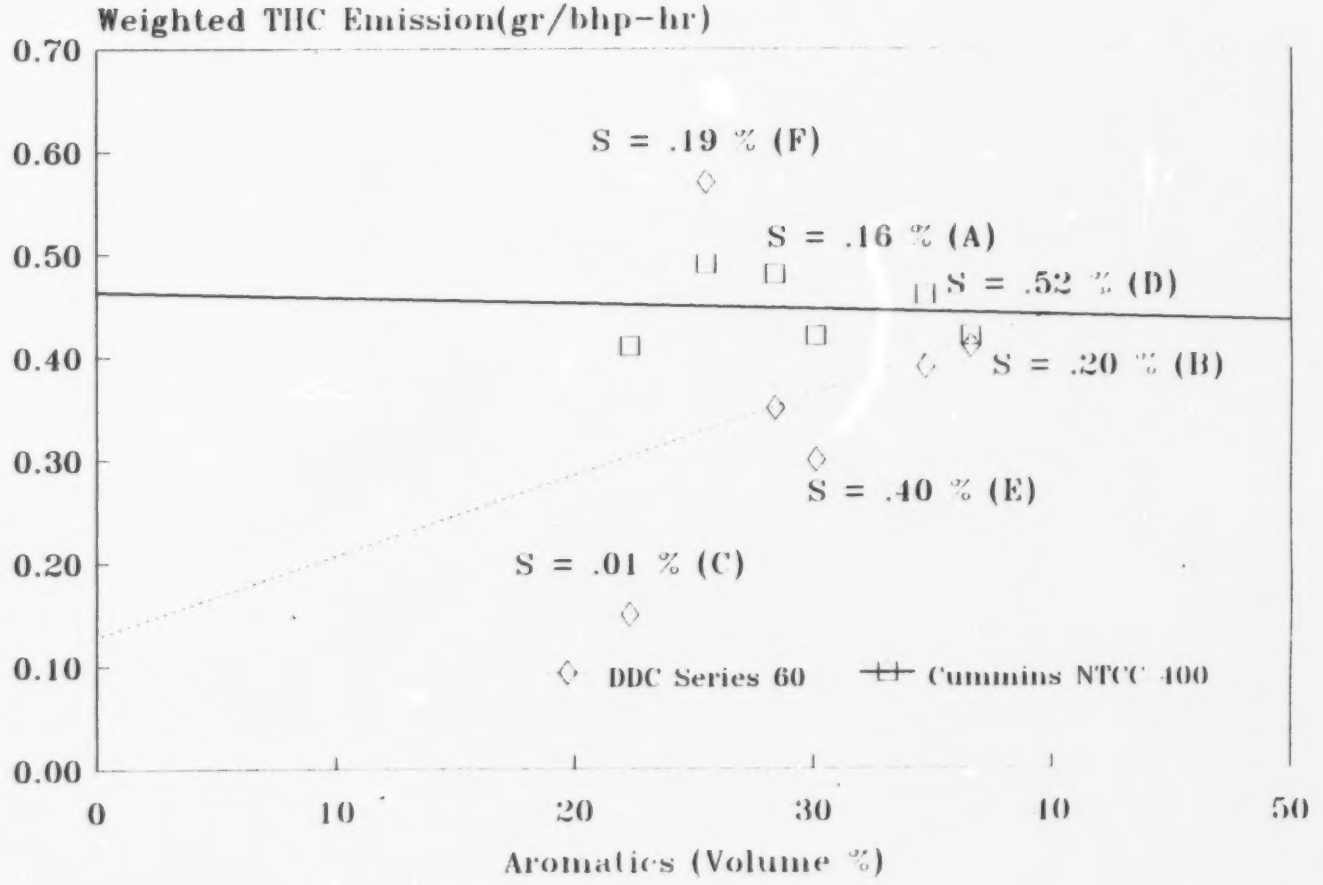


Figure 6.4.1

AET-ORTECH International

Emission Impact
Diesel Fuel Quality

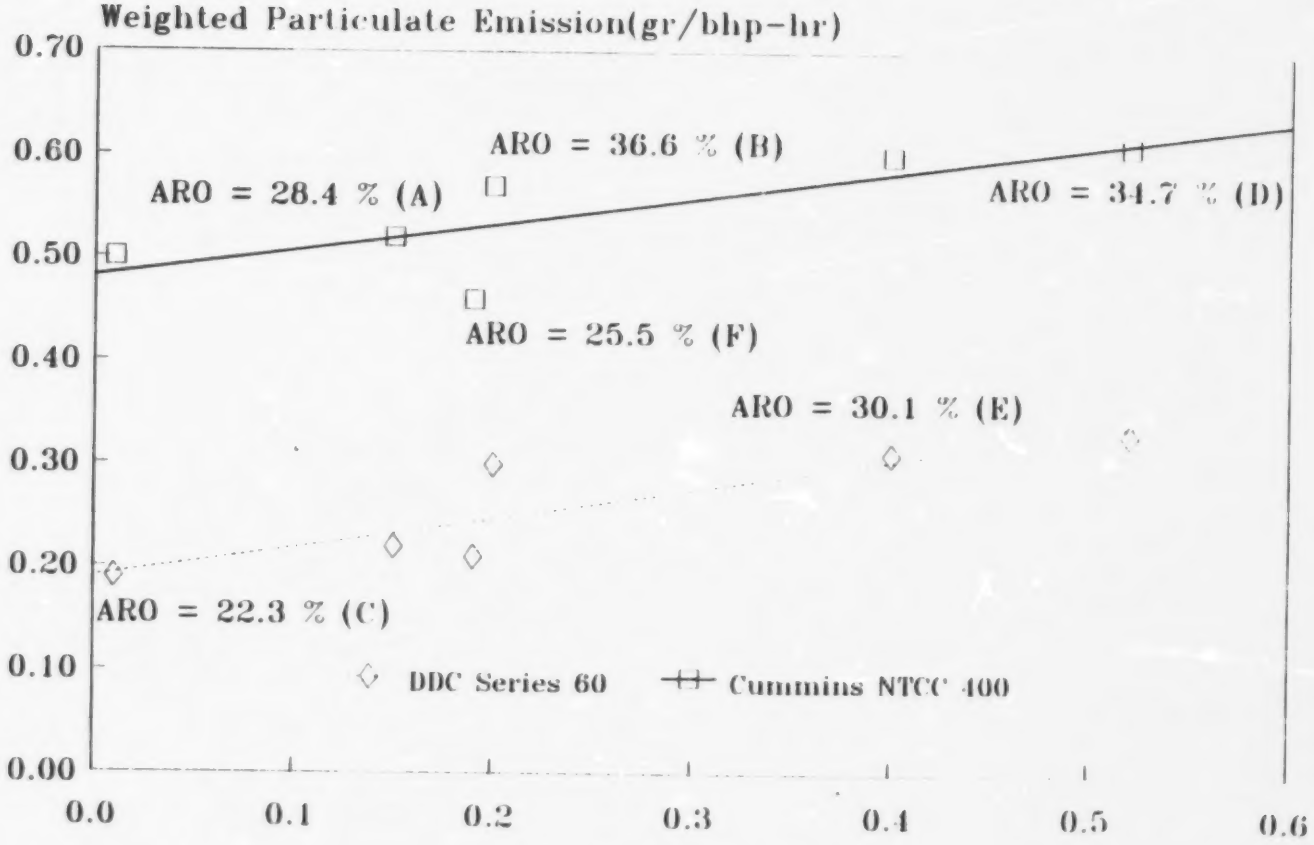


Figure 6.4.5

AET-ORTECH International

Emission Impact
Diesel Fuel Quality

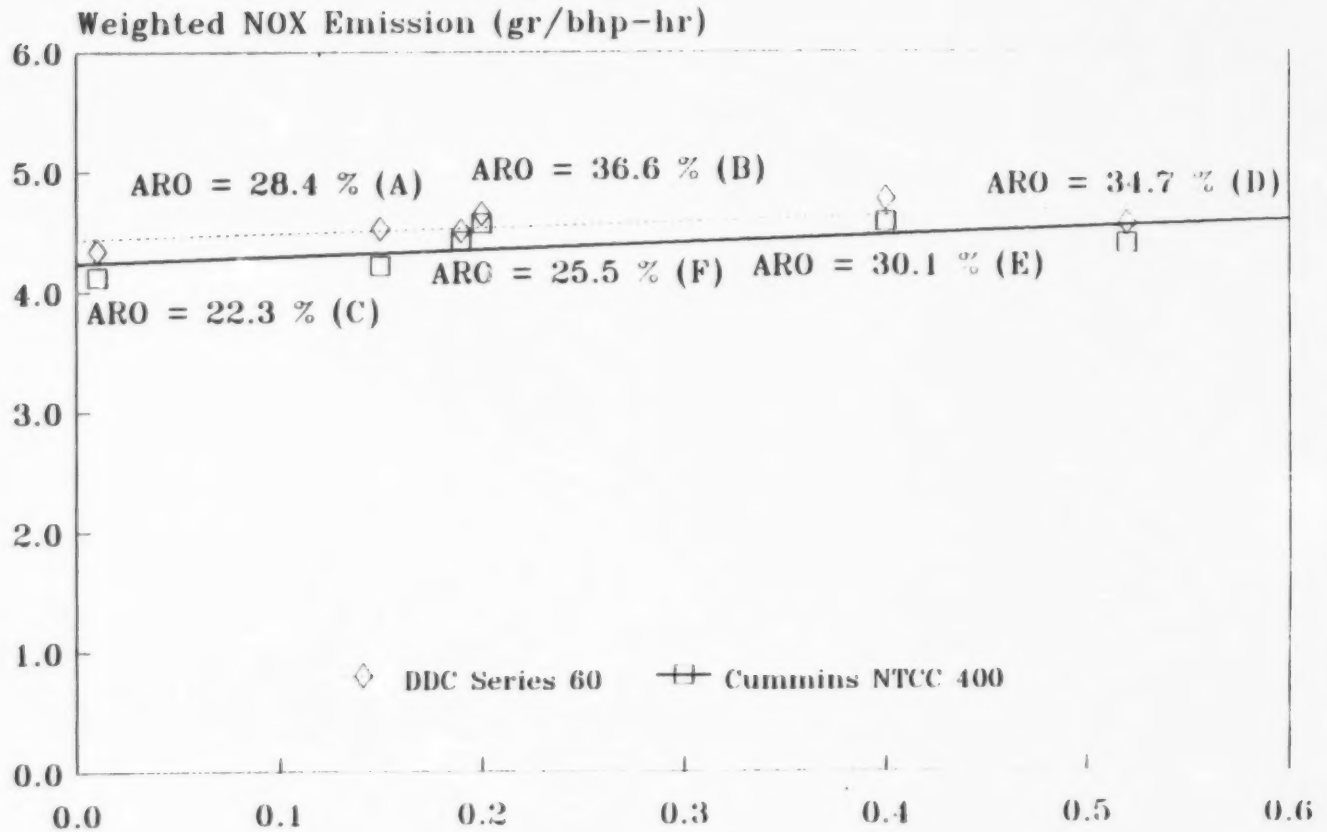


Figure 6.4.6

AET-ORTECH International

Emission Impact
Diesel Fuel Quality

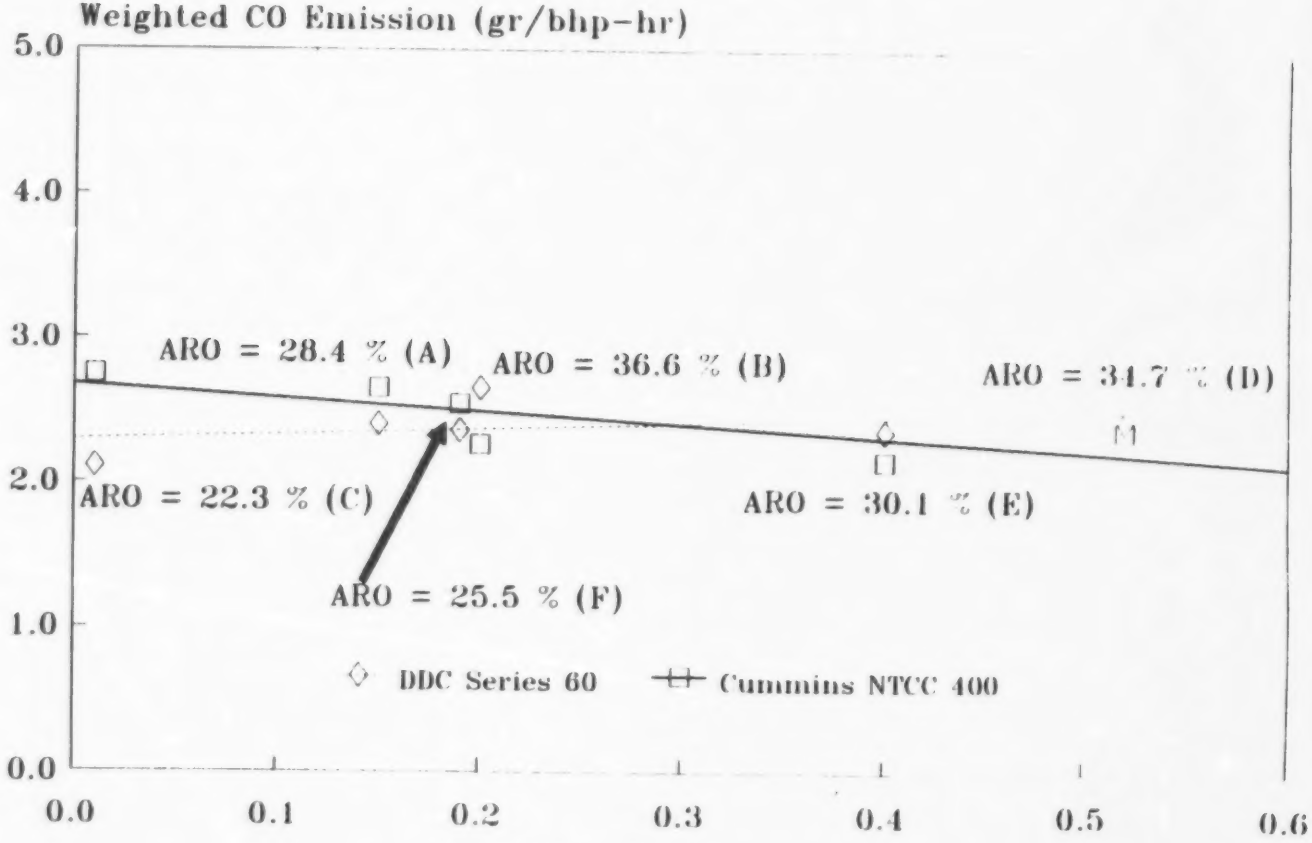


Figure 6.4.7

AET-ORTECH International

Emission Impact
Diesel Fuel Quality

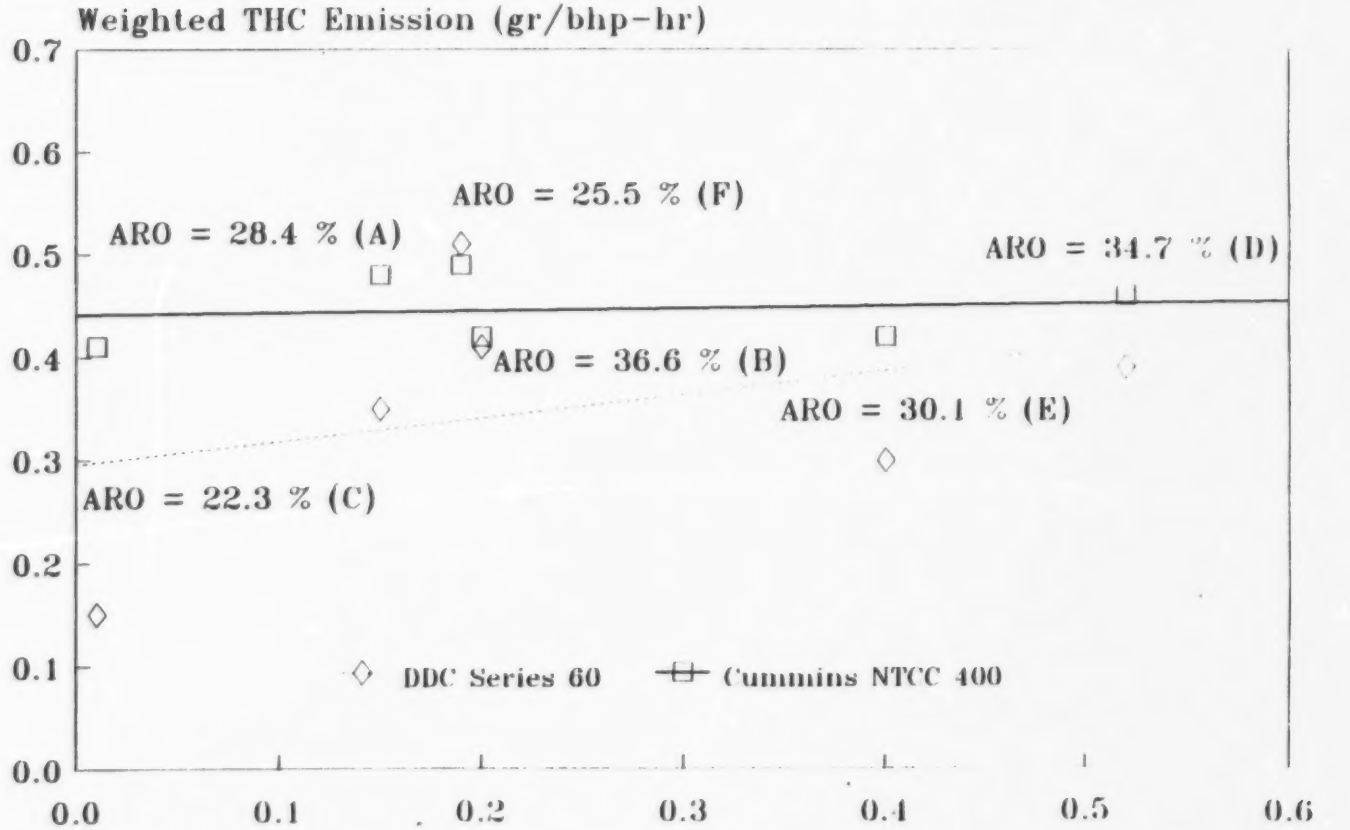


Figure 6.4.8

AET-ORTECH International

Emission Impact
Diesel Fuel Quality

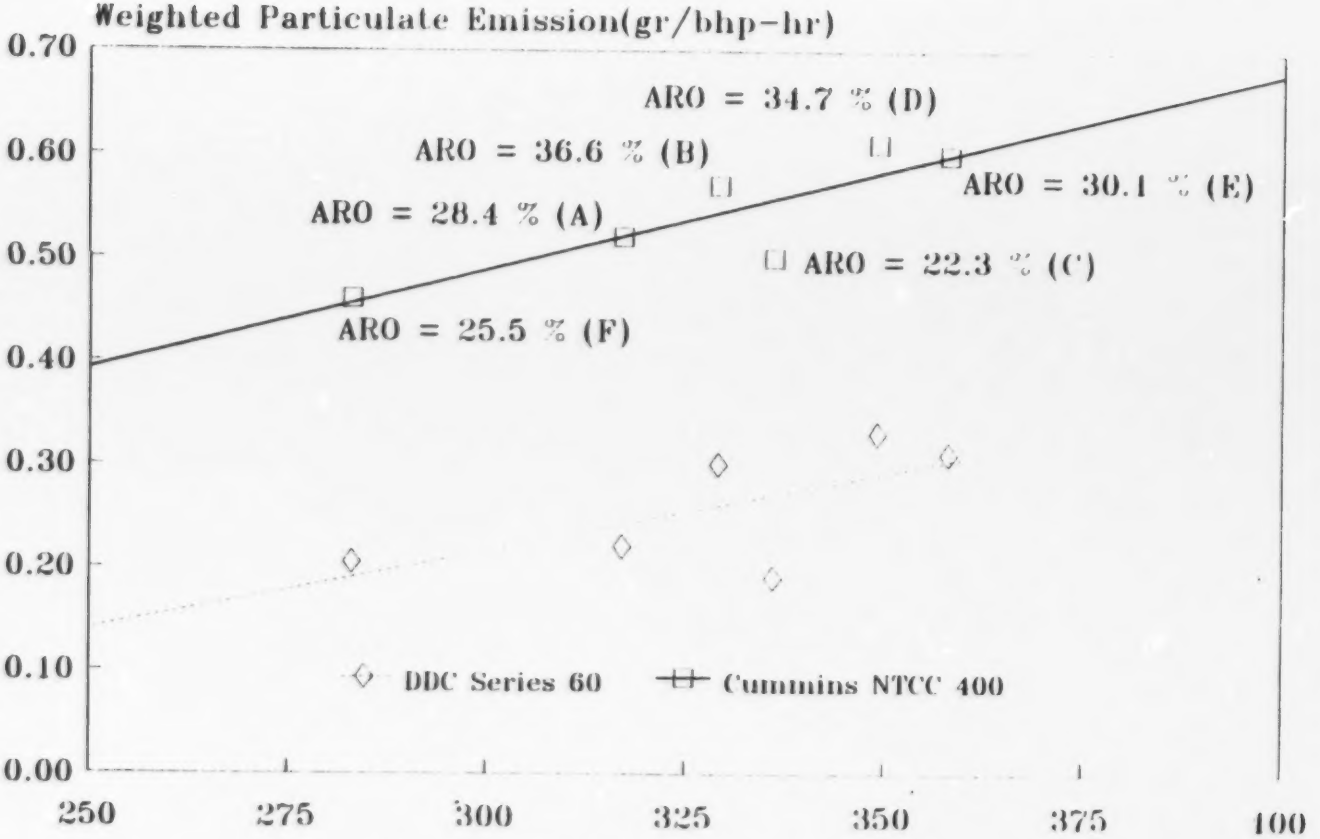


Figure 6.4.9

AET-ORTECH International

Emission Impact
Diesel Fuel Quality

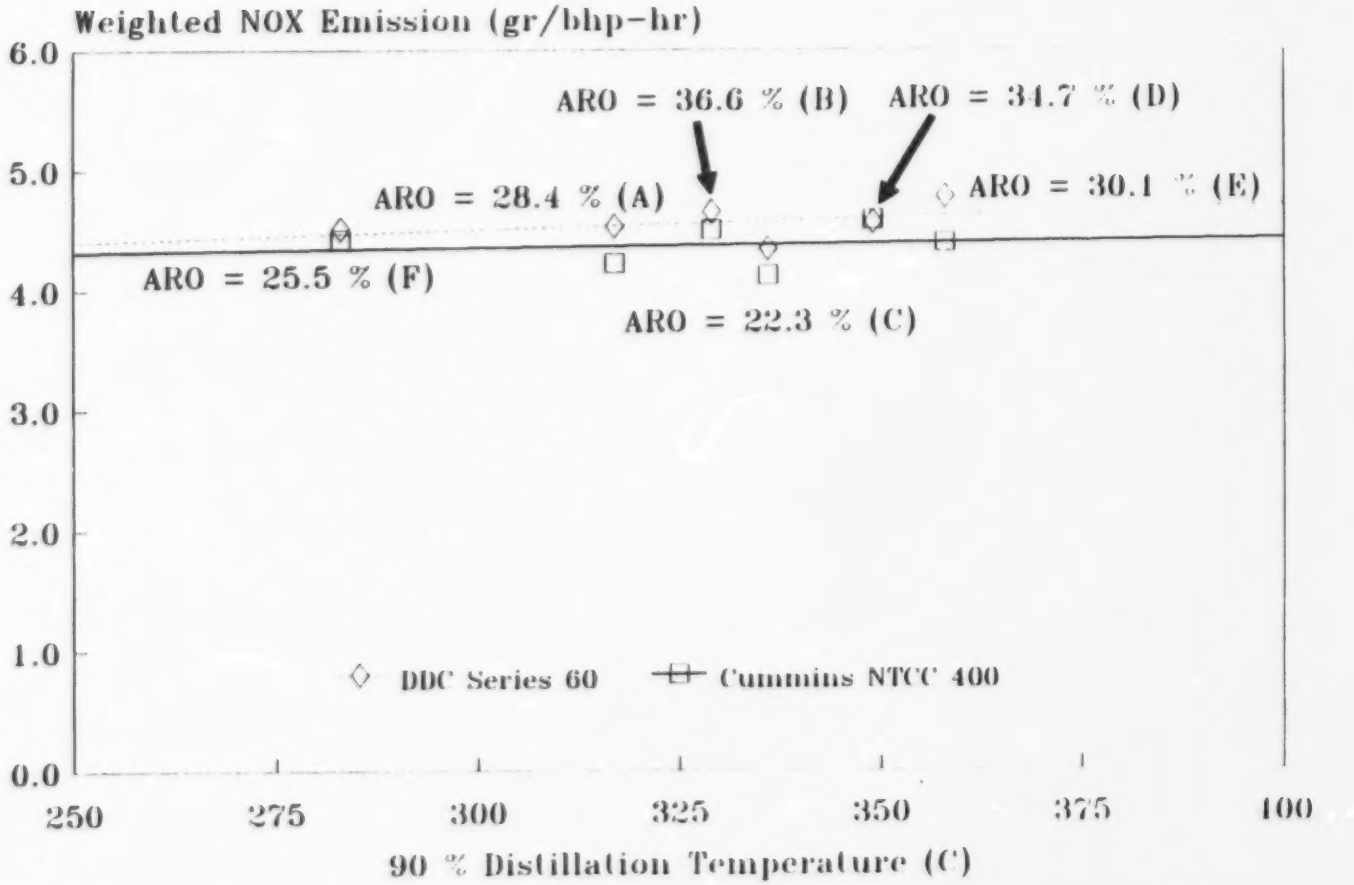


Figure 6.4.10

AET-ORTECH International

Emission Impact
Diesel Fuel Quality

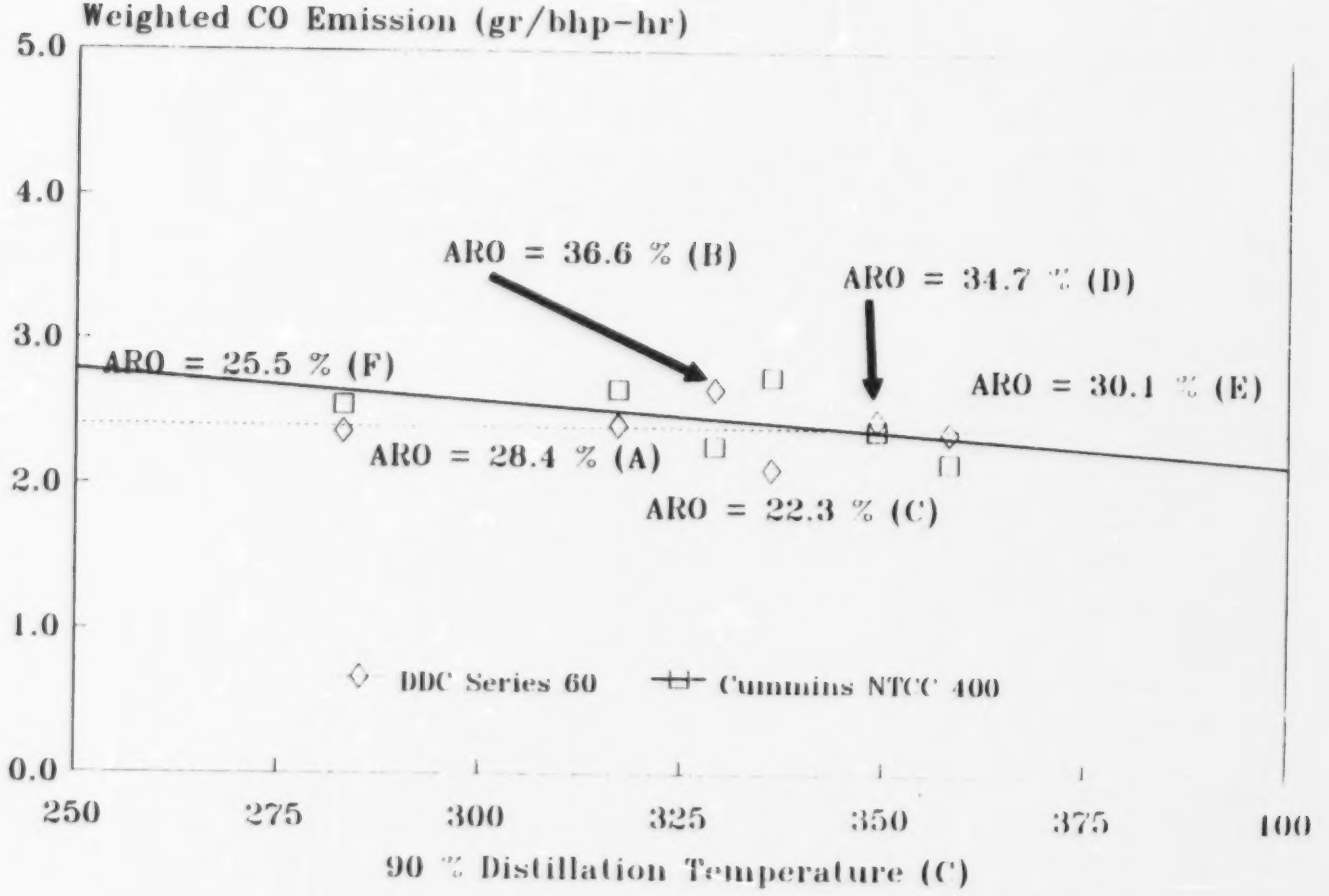


Figure 6.4.11

AET-ORTECH International

Emission Impact
Diesel Fuel Quality

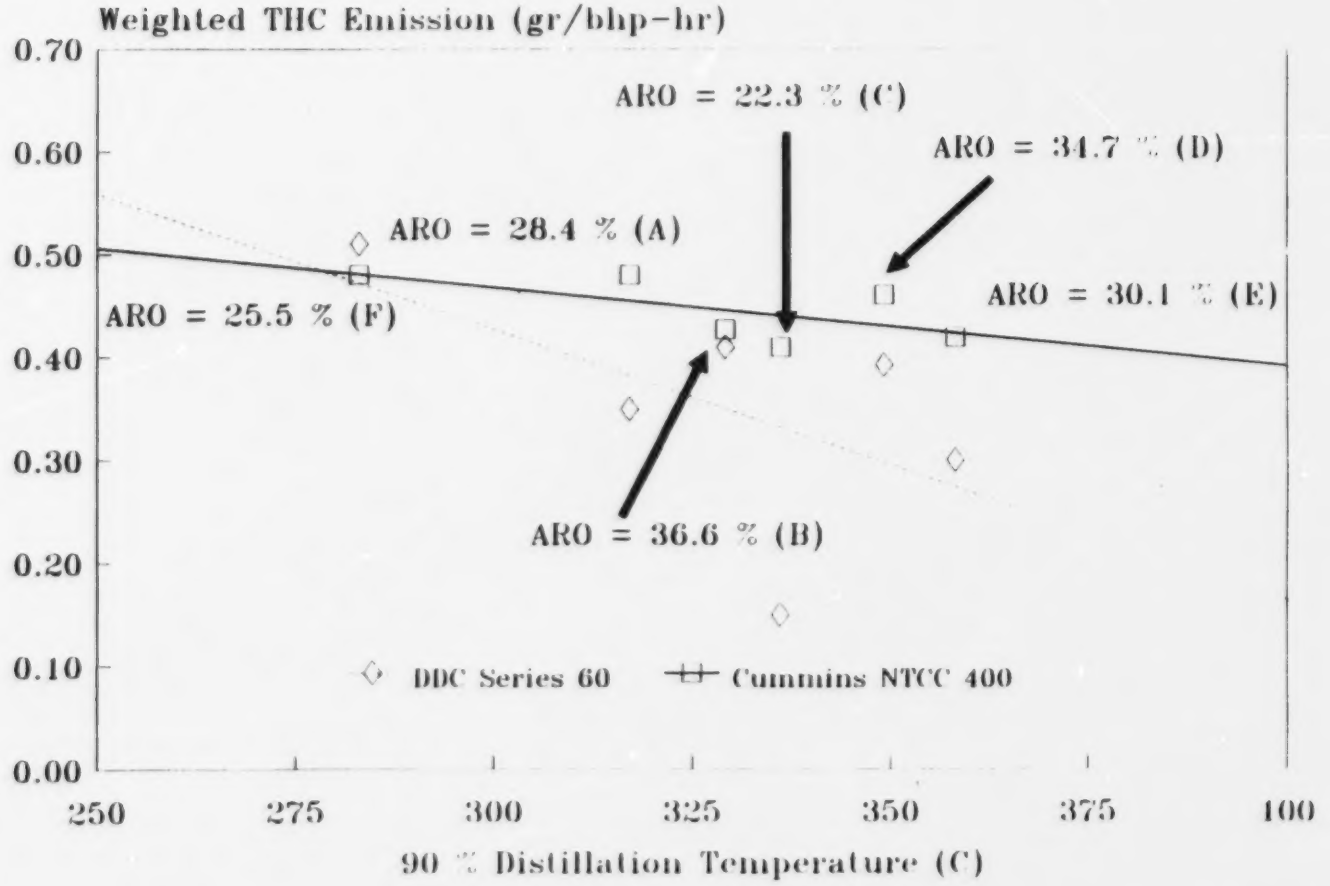


Figure 6.4.12

AET-ORTECH International

APPENDIX A: Heavy Duty Diesel Emission Test Facility.

FACILITIES AND EQUIPMENT

Test Cells

ORTECH has eight engine test cells designed for both spark and compression ignited engines. Computer controlled dynamometers provide transient as well as steady state operation capabilities. Dynamometers available include 5 Eaton eddy current dynamometers (175 HP to 500 HP), 1 G.E. eddy current dynamometer (500 HP), 3 Go-Power water brake dynamometers and an MCC 40 HP motoring DC dynamometer.

All test cells are rated for diesel fuel. Six test cells are rated for gasoline as well as natural gas and other alternative fuels.

All test cells and engines are instrumented to measure temperatures, pressures, etc. and other required parameters.

A Ricardo single cylinder research engine is set up with a motoring dynamometer and is used primarily for basic engine combustion studies. This engine can be equipped with various cylinder heads to allow research in either spark or compression ignition modes.

Four test cells are connected to a Hewlett-Packard 1000 series E computer. Engine speed and torque are controlled and updated five times per second. The system includes cycle building which enables ORTECH to run the modified EPA heavy duty diesel engine cycle, New York and LA bus cycles, advanced design bus cycle and any other transient cycles as required. The modified EPA cycle is the same as the standard cycle with the motoring torque segments replaced with idle loading. The dynamometer and throttle control coefficients can be optimized so that EPA heavy- duty transient cycle regression parameters are met. Lab to lab correlation of EPA transient cycle between ORTECH and an engine manufacturer has shown data correlation between the two cycles within $\pm$5%.

A MACSYM 150 computer system is used for collecting data and performing the EPA regression analysis for cycle validations. Data collected can then be transferred to an IBM PC for further detailed calculations and analysis. Both computer systems are used for real-time data acquisitions, processing and analysis. In specialized applications such as combustion studies, a Norland processing digital oscilloscope is utilized to acquire, process and analyze waveforms. Data will then again be transferred to an IBM PC where sophisticated software is available for analytical analysis.

Emissions

ORTECH has the capability to characterize the emissions from a wide range of engines under steady-state or transient cycle operation, using a 2000 cfm PDP-CVS double dilution tunnel. This system was built according to EPA specifications.

The Beckman gaseous emissions bench in conjunction with the computer system, records real time concentration of carbon dioxide, carbon monoxide, total hydrocarbons and oxides of nitrogen. The particulate bench provides controlled proportional sampling of particulate matter. Particulate filters are also characterized for soluble and insoluble fractions. Calibration of these benches is performed regularly according to the EPA procedure or good engineering practice.

Total sulphur concentration in the dilution tunnel is determined using the controlled condensate method. Subsequent analysis by spectrophotometer allows for the differentiation of SO and H_2SO_4.

Particulate filters can also be analyzed to determine the sulphate collected. Attached is a flow chart showing the procedure used. After SOF has been determined, the filters were ammoniated to form ammonium sulphate ($(NH_4)2SO_4$). Two methods were used to determine the amount of ammonium sulphate:

- The ammonium sulphate was extracted from the filter with a 50% IPA and water solution and the IPA solution was analyzed by Ion Chromatograph.
- The filters were weighed.

Method 1 is known as Extract IC analysis and Method 2 is known as gravimetric analysis.

Exhaust aldehydes are determined using the DNPH (2-4 dinitrophenyl-hydrazine) cartridge method. Cartridges are extracted and analyzed using a high performance liquid chromatograph (HPLC) for a variety of aldehydes.

For metals analysis of the exhaust emissions, a modified EPA #5 sampling train is used to collect samples from the dilution tunnel. The filters and impinger solutions are then analyzed by DC plasma emission spectrophotometry to determine the metal composition and concentration.

A mini dilution tube is used to collect particulate samples for the Ames Mutagenicity Assay and determination of Polycyclic Aromatic Hydrocarbons (Pah's). The Ames Assay can be performed with a number of Salmonella tester strains with and without metabolic activation. Pah's are analyzed by HPLC.

ORTECH has over 10 years experience in the sampling and analysis of diesel particulate matter, including contributions to CRC - APRAC Symposium on characterization of diesel particulate emissions. There are quality assurance procedures in place to assure the highest degree of reliability of the data collected.

APPENDIX B: Transient Emission Test Procedures.

Modified EPA Transient Emission Testing

Each series of modified EPA transient cycle emission tests are conducted over a two day schedule.

The first day is dedicated to tunnel conditioning, engine performance verification and instrumentation calibration. Day one consists of operating the engine over two modified EPA transient cycles. The first cycle is a verification cycle in which specific engine operating, dilution tunnel and particulate sampling temperatures and pressures are monitored. The second cycle is an emission cycle in which all emission data is collected. The emission cycle verifies that all the emission analyzers are operating properly and are on the appropriate ranges. Between each cycle the engine is soaked for 20 minutes.

The second day is scheduled for transient cycle emission testing. Day two consists of operating the test engine over one cold cycle, five hot cycles followed by one verification cycle. Emission data is only collected over the cold and hot cycles.

During the engine soak period, the engine is turned off. The dilution tunnel positive displacement pump is left operating. The exhaust pipe connecting the engine manifold to the dilution tunnel is disconnected at the turbocharger. The exhaust pipe is detached as a precautionary procedure to prevent any oil or oil vapour from the valves from contaminating the exhaust system.

Following the initial cycle emission test on day 2, the engine is allowed to soak for 20 minutes, during which time the engine oil temperature is monitored and recorded. Subsequent engine soaks between each emission transient cycle will end when the engine oil temperature reaches that of the temperature recorded at the end of the first engine soak.

The transient emission testing protocol is as follows:

Transient Emission Testing

Day 1 - Afternoon - Tunnel Conditioning

Tunnel conditioning shall be within 24 hours of emissions testing.

A. Operate the engine until the oil pan temperature reaches 110 degrees Fahrenheit.

B. Operate the engine at maximum horsepower for 5 minutes; verify engine performance and record all pertinent engine parameters at this load-speed within the 5 minutes.

C. 20 Minute Soak
- Turn the engine off
- Leave the Dilution Tunnel on
- Disconnect the exhaust at the turbocharger.

Reconnect the exhaust at the turbocharger

D. Complete (1) Modified EPA Transient Cycle as a Verification Cycle.

Disconnect the exhaust at the turbocharger

E. Turn the engine off and cold soak for 20 minutes.

Reconnect the exhaust at the turbocharger

F. Complete (1) Modified EPA Transient Cycle and collect all emissions data. This cycle will verify that all the emissions analyzers are operating properly and are on the appropriate ranges.

Reconnect the exhaust at the turbocharger

Day 2 Morning - Emissions Tests

A. Check all critical temperatures, the cell temperature should be 25 $\pm$ 5 Centigrade.

B. Run COLD CYCLE (#1) (collect all emissions data).

C. 20 Minute Soak
- Turn the engine off
- Leave the Dilution Tunnel on
- Disconnect the exhaust at the turbocharger
- Monitor and record the engine oil temperature

Reconnect the exhaust at the turbocharger

D. Run HOT CYCLE (#2) (collect all emissions data).

Disconnect the exhaust at the turbocharger

E. Soak the engine until the engine oil temperature reaches the same temperature recorded at the end of the first 20 minute soak (Part C).

Reconnect the exhaust at the turbocharger

F. Run HOT CYCLE (#3) (collect all emissions data)

Disconnect the exhaust at the turbocharger

G. Soak the engine until the engine oil temperature reaches the4 same temperature recorded at the end of the first 20 minute soak (Part C).

Reconnect the exhaust at the turbocharger

H. Run HOT CYCLE (#4) (collect all emissions data)

Disconnect the exhaust at the turbocharger

I. Soak the engine until the engine oil temperature reaches the same temperature recorded at the end of the first 20 minute soak (Part C).

Reconnect the exhaust at the turbocharger

J. Run HOT CYCLE (#5) (Collect all emissions data).

Disconnect the exhaust at the turbocharger

K. Soak the engine until the engine oil temperature reaches the same temperature recorded at the end of the first 20 minute soak (Part C).

Reconnect the exhaust at the turbocharger

L. Run HOT CYCLE (#6) (Collect all emissions data).

Disconnect the exhaust at the turbocharger

M. Soak the engine until the engine oil temperature reaches the same temperature recorded at the end of the first 20 minute soak (Part C).

Reconnect the exhaust at the turbocharger

N. Complete (1) Modified EPA Transient Cycle as a Verification Cycle, collecting all pertinent temperatures and pressures.

Reconnect the exhaust at the turbocharger.

APPENDIX C: Engine Performance Data -
Steady State and Transient.

Tables and Figures Referred to in "Section 4.2 - NTC 400" in Report.

Date : 88-05-19 FILE : \FCF\NTCC400\2PT CERT

2 POINT COMPARISON

Engine Model : Cummins NTCC 400
Engine ID No. : 10780756
Engine Hours : 606.6
Date : March 16/1988
Operator : IC/WB
Project Manager : Kong Ha
Test Cell : B

	Cummins	ORF	Difference	(%)	Cummins	ORF	Difference	(%)
Engine Speed (rpm)	2100	2100	0	0.0	1300	1300	0	0.0
Torque (ft-lbs)	966.62	1000.1	33.5	3.5	1222.1	1222.5	0.4	0.0
Fuel Rate (lb/hr)	148.5	152.2	3.7	2.5	110.0	106.7	-3.3	-3.0
Brake Horse Power	386.2	400.9	14.7	3.8	302.3	300.3	-2.0	-0.7
BSFC (lb/bhp-hr)	0.385	0.380	-0.005	-1.3	0.364	0.355	-0.009	-2.3
Wet Barometer (in Hg)	29.481	29.43	-0.051		29.483	29.43	-0.05	
Vapor Pressure (in Hg)	0.70	0.27	-0.42		0.70	0.27	-0.43	
Wet Bulb (F)	----	56	----			56	----	
Dry Bulb (F)	----	73	----			73	----	
Intake Air (F)	77	78	1		79	80	1	
Intake Manifold (F)	190	191	1		174	173	-1	
Engine Water In (F)	125	128	3		116	118	2	
Engine Water Out (F)	181	178	-3		178	177	-1	
Oil Pan (F)	225	224	-1		223	222	-1	
Fuel Temp at Pump (F)	103	96	-7		103	89	-14	
Exhaust Stack (F)	892	1016	124		1133	1198	65	
Test Cell (F)	104	106	2		102	102	0	
Intake Restriction (in H20)	-20.0	-22.6	-2.6		-4.9	-3.5	1.4	
Intake Manifold (psi)	22.0	20	-2.0		13.3	14.0	0.7	
Exhaust Back Press.(in Hg)	2.4	3.4	1.0		1.0	1.4	0.4	
Rail (psi)	173	180	7.0		112	112	0.0	
Oil Rifle Pressure (psi)	42	41.6	-0.4		35	33.6	-1.4	

Mass Fuel Consumption (Weight Scale)

Inital Wt 411.2 lbs
Final Wt. 395.7 lbs
15.5 lbs

Time 6 Min
4.00 Sec

Fuel Consumption 153.3 lb/hr
Fuel Consumption 152.2

Mass Fuel Consumption (Weight Scale)

Inital Wt. 387.1 lbs
Final Wt. 376.3 lbs
10.8 lbs

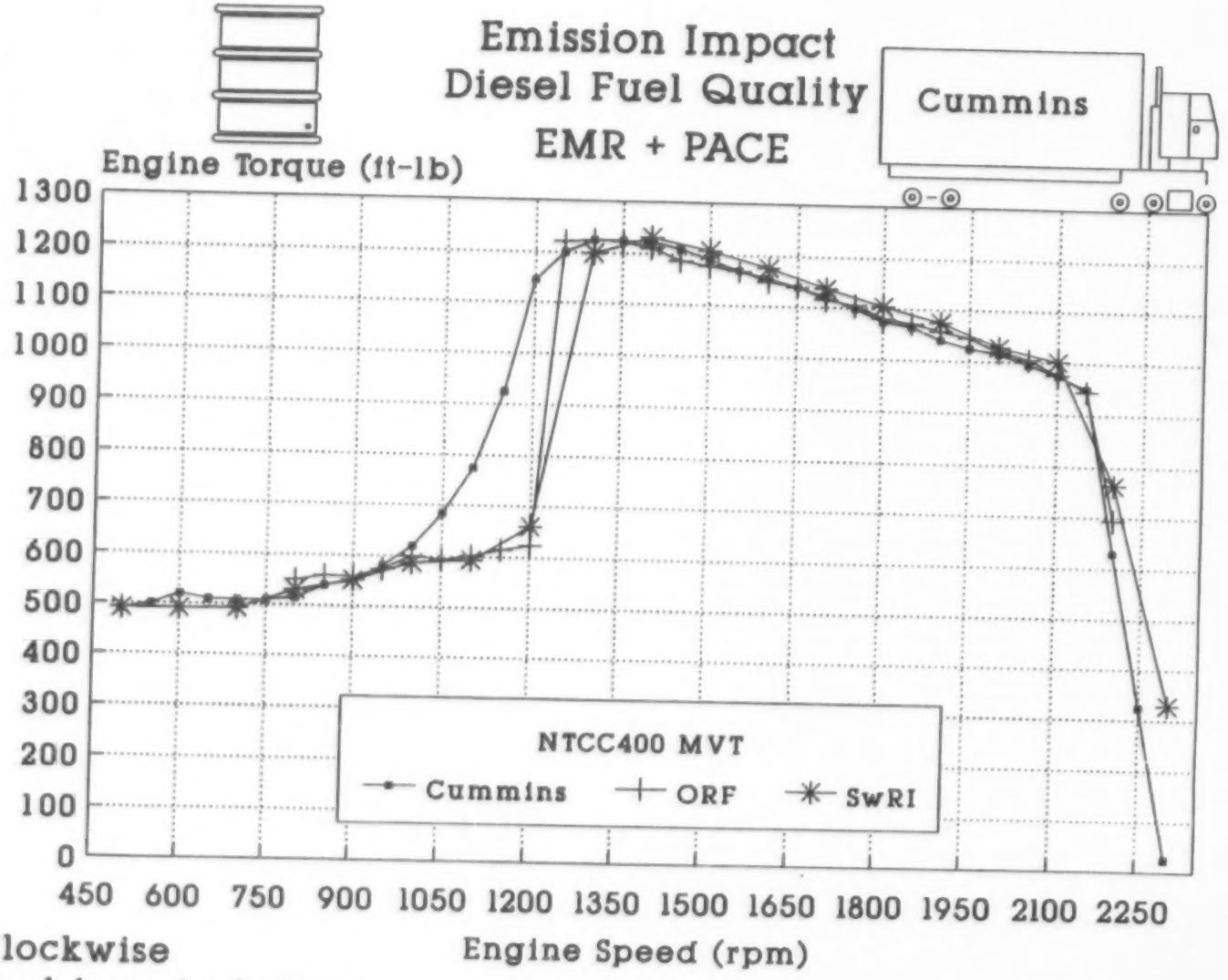
Time 6 Min
4.00 Sec

Fuel Consumption 106.8 lb/hr

TABLE C.4.2.1

Steady-state Performance Comparison Between Cummins and ORF

FIGURE C.4.2.1: Manual Torque Curve.



1)Clockwise
2)Fuel from fuel drum

April 6, 1988 AETC-ORF

@Date : 88-05-31 FILE : \FCF\NTCC400\~~tc2~~ TC May 30 88

MANUAL TORQUE CURVE

Engine Model : Cummins NTC 400
Engine ID No. : 10780756
Engine Hours :
Date : May 30, 1988
Operator : AB + WD
Project Manager : Kong Ha
Test Cell: 8

Barometric Pressure ("Hg) :
Wet Bulb Temp (F) :
Dry Bulb Temp. (F) :

Rated Power (Hp) : 391
Engine Speed (rpm) : 2050
Fuel Consumption (lb/hr) : 155.2
Inlet Depress.("H2O) :
Exhaust B.P. ("Hg) :

Intake Air (F) :
Relative Humidity (%) :
Maximum Torque (lb-ft) : 1210.0
Horsepower (BHP) : 299.5
Engine Speed : 1300
Fuel Consumption (lb/hr) : 107.9
Curb Idle Speed (rpm) : 650
Governed Speed (rpm) : 2300
Max EPA Cycle Speed (rpm): 2232

Map Technique Used : Manual,Speed Control,Clockwise fuel from fuel drum

Cummins ORF
Reference Torque Curve May 30, 1988

Speed (rpm)	Torque (lb-ft)	BHP	Torque (lb-ft)	Difference (lb-ft)	Difference (%)	BHP hp	Difference hp	Difference (%)
500	490	46.6	---	---	---	---	---	---
550	500	52.4	---rotex destructed--			---rotex destructed--		
600	520	59.4	---	---	---	---	---	---
650	510	63.1	---	---	---	---	---	---
700	510	68.0	534	-24	-5	71.2	-3	-5
750	510	72.8	535	-25	-5	76.4	-4	-5
800	515	78.4	537	-22	-4	81.8	-3	-4
850	540	87.4	545	-5	-1	88.2	-1	-1
900	550	94.2	553	-3	-1	94.8	-1	-1
950	580	104.9	573	7	1	103.6	1	1
1000	620	118.1	580	40	6	110.4	8	6
1050	685	136.9	590	95	14	118.0	19	14
1100	775	162.3	610	165	21	127.8	35	21
1150	925	202.5	634	291	31	138.8	64	31
1200	1145	261.6	1187	-42	-4	271.2	-10	-4
1250	1200	285.6	1194	6	1	284.2	1	0
1300	1225	303.2	1210	15	1	299.5	4	1
1350	1225	314.9	1206	19	2	310.0	5	2
1400	1222	325.7	1185	37	3	315.9	10	3
1450	1210	334.1	1162	48	4	320.8	13	4
1500	1190	339.9	1147	43	4	327.6	12	4
1550	1170	345.3	1133	37	3	334.4	11	3
1600	1155	351.9	1128	27	2	343.6	8	2
1650	1140	358.1	1113	27	2	349.7	8	2
1700	1120	362.5	1097	23	2	355.1	7	2
1750	1100	366.5	1096	4	0	365.2	1	0
1800	1075	368.4	1073	2	0	367.7	1	0
1850	1065	375.1	1063	2	0	374.4	1	0
1900	1040	376.2	1044	-4	-0	377.7	-1	-0
1950	1025	380.6	1037	-12	-1	385.0	-4	-1
2000	1015	386.5	1022	-7	-1	389.2	-3	-1
2050	995	388.4	1002	-7	-1	391.1	-3	-1
2100	975	389.9	973	2	0	389.1	1	0
2150	950	388.9	951	-1	-0	389.3	-0	-0
2200	630	263.9	720	-90	-14	301.6	-38	-14
2250	325	139.2	368	-43	-13	157.7	-18	-13
2300	25	10.9	114	-89	-356	49.9	-39	-356
Maximium	1225	389.9	1210			391.1		

TABLE C.4.2.2

Manual Torque Curve for Cummins NTCC-400

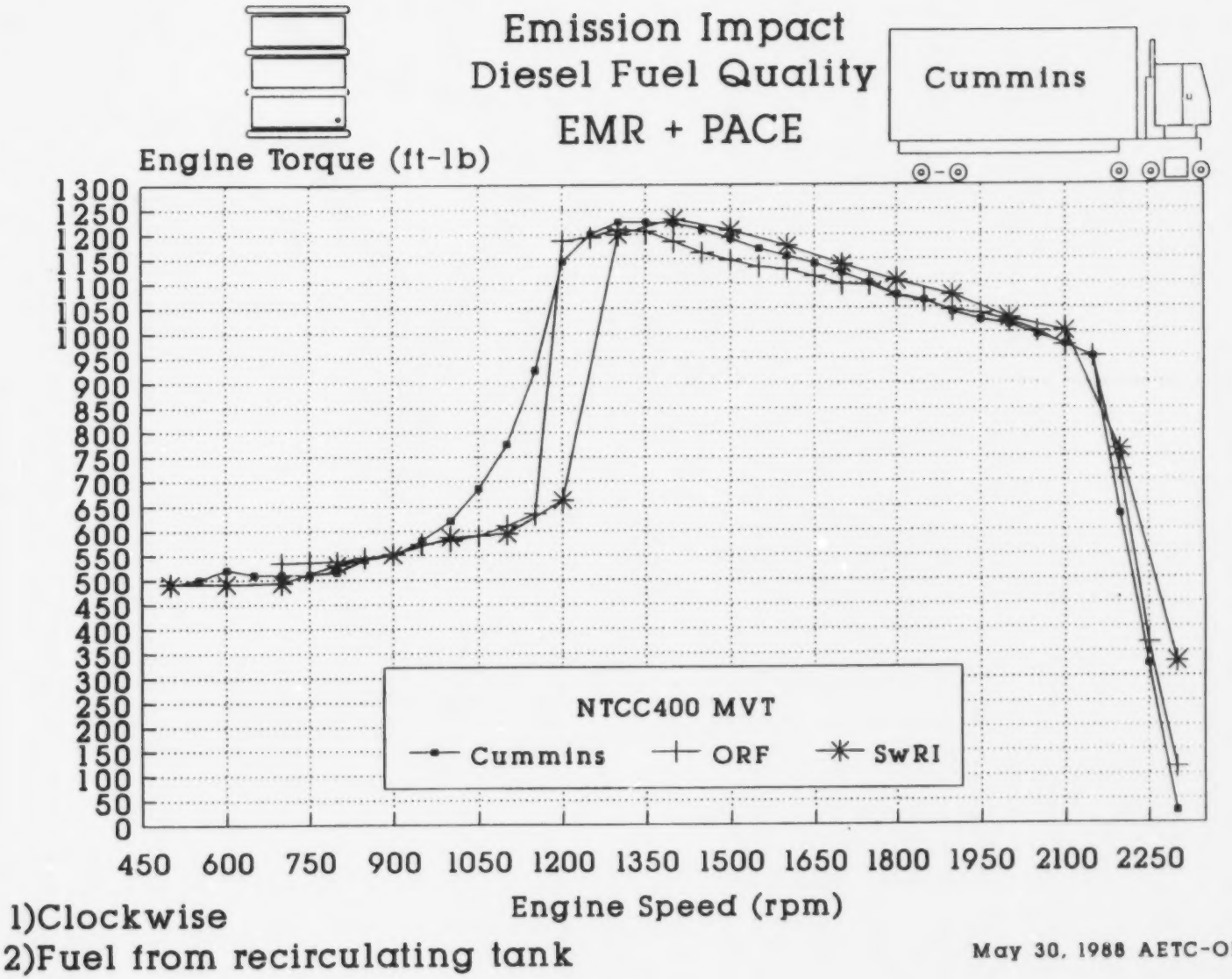


FIGURE C. 4.2.2 Manual Torque Curve for Cummins NTCC-400

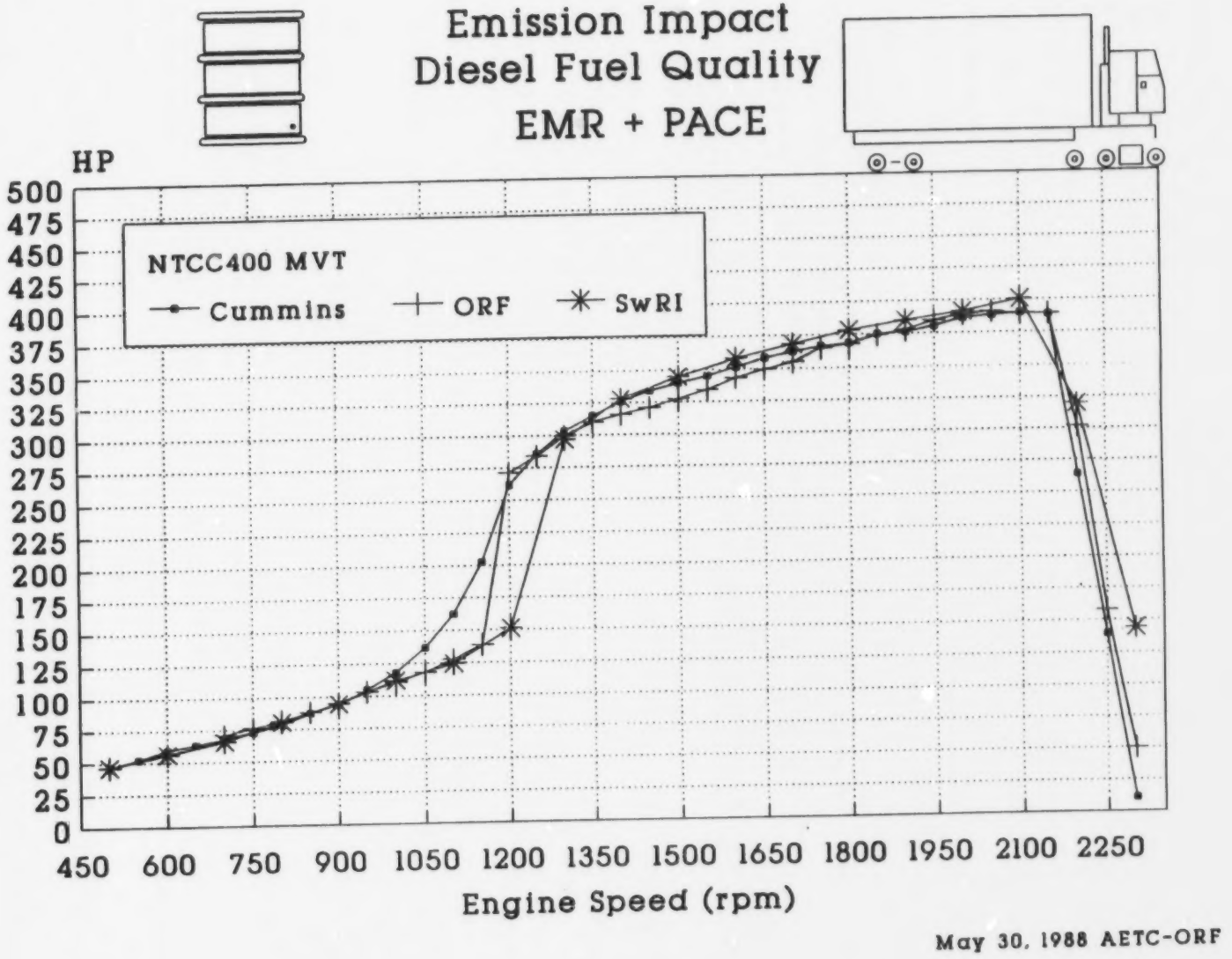


FIGURE C .4.2.3 HP Curve for Cummins NTCC-400

2 POINT COMPARISON

Engine Model : Cummins NTCC 400
Engine ID No. : 10780756
Engine Hours : 606.6
Date : May 30/1988
Operator : AB/WD
Project Manager : Kong Ha
Test Cell : 8

	Cummins	ORF	Difference	(%)	Cummins	ORF	Difference	(%)
Engine Speed (rpm)	2100	2100	0	0.0	1300	1300	0	0.0
Torque (ft-lbs)	966.62	986.6	20.0	2.1	1222.1	1210.4	-11.7	-1.0
Fuel Rate (lb/hr)	148.5	155.2	6.6	4.5	110.0	107.9	-2.1	-1.9
Brake Horse Power	386.2	394.5	8.3	2.1	302.3	299.6	-2.7	-0.9
BSFC (lb/bhp-hr)	0.385	0.393	0.009	2.3	0.364	0.360	-0.004	-1.0
Wet Barometer (in Hg)	29.481	29.49	0.009		29.483	29.49	0.01	
Vapor Pressure (in Hg)	0.70							
Wet Bulb (F)	----	63	----			63	----	
Dry Bulb (F)	----	75	----			75	----	
Intake Air (F)	77	83	6		79	81	2	
Intake Manifold (F)	190	192	2		174	173	-1	
Engine Water In (F)	125	135	10		116	108	-8	
Engine Water Out (F)	181	178	-3		178	177	-1	
Oil Pan (F)	225	207	-18		223	221	-2	
Fuel Temp at Pump (F)	103	110	7		103	101	-2	
Exhaust Stack (F)	892	1017	125		1133	1199	66	
Test Cell (F)	104	111	7		102	114	12	
Intake Restriction (in H20)	-20.0	-23.1	-3.1		-4.9	-5.6	-0.7	
Intake Manifold (psi)	22.0	18.2	-3.8		13.3	12	-1.3	
Exhaust Back Press.(in Hg)	2.4	3.65	1.3		1.0	1.3	0.3	
Rail (psi)	173	180	7.0		112	115	3.0	
Oil Rifle Pressure (psi)	42	39.7	-2.3		35	31.1	-3.9	

Mass Fuel Consumption (Weight Scale)

Inital Wt 259.7 lbs
Final Wt. 244.3 lbs
15.4 lbs

Time 5 Min 0.00 Sec

Fuel Consumption 184.8 lb/hr
Fuel Consumption 155.16

Mass Fuel Consumption (Weight Scale)

Inital Wt. 235.9 lbs
Final Wt. 220.5 lbs
15.4 lbs

Time 8 Min 33.67 Sec

Fuel Consumption 107.9 lb/hr

TABLE C.4.2.3

Performance Data from Cummins NTCC-400

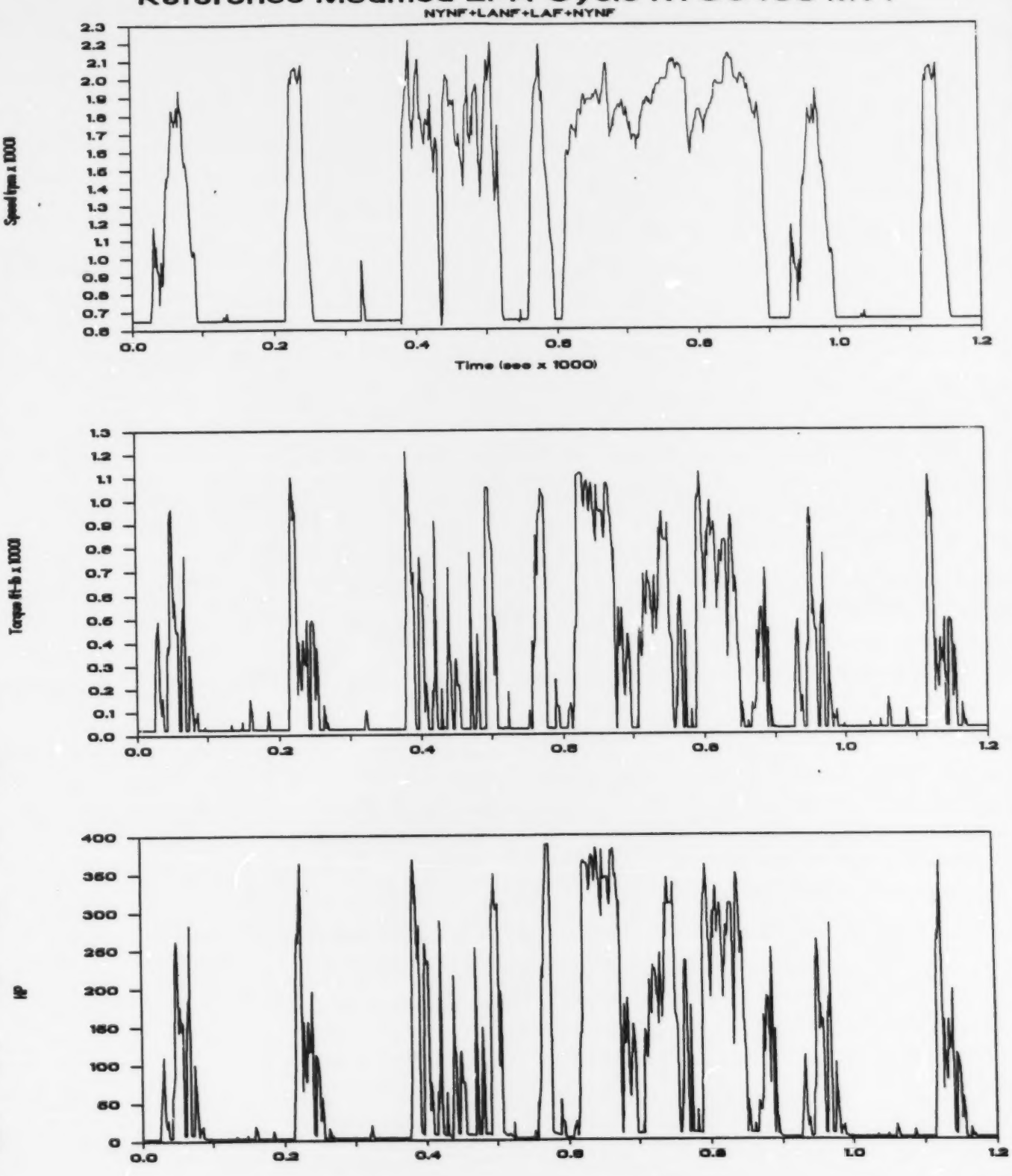

Reference Modified EPA Cycle NTCC400 MVT
NYNF+LANF+LAF+NYNF
Speed kpm x 1000
Time (sec x 1000)
Torque ft-lb x 1000
HP

FIGURE C.4.2.4

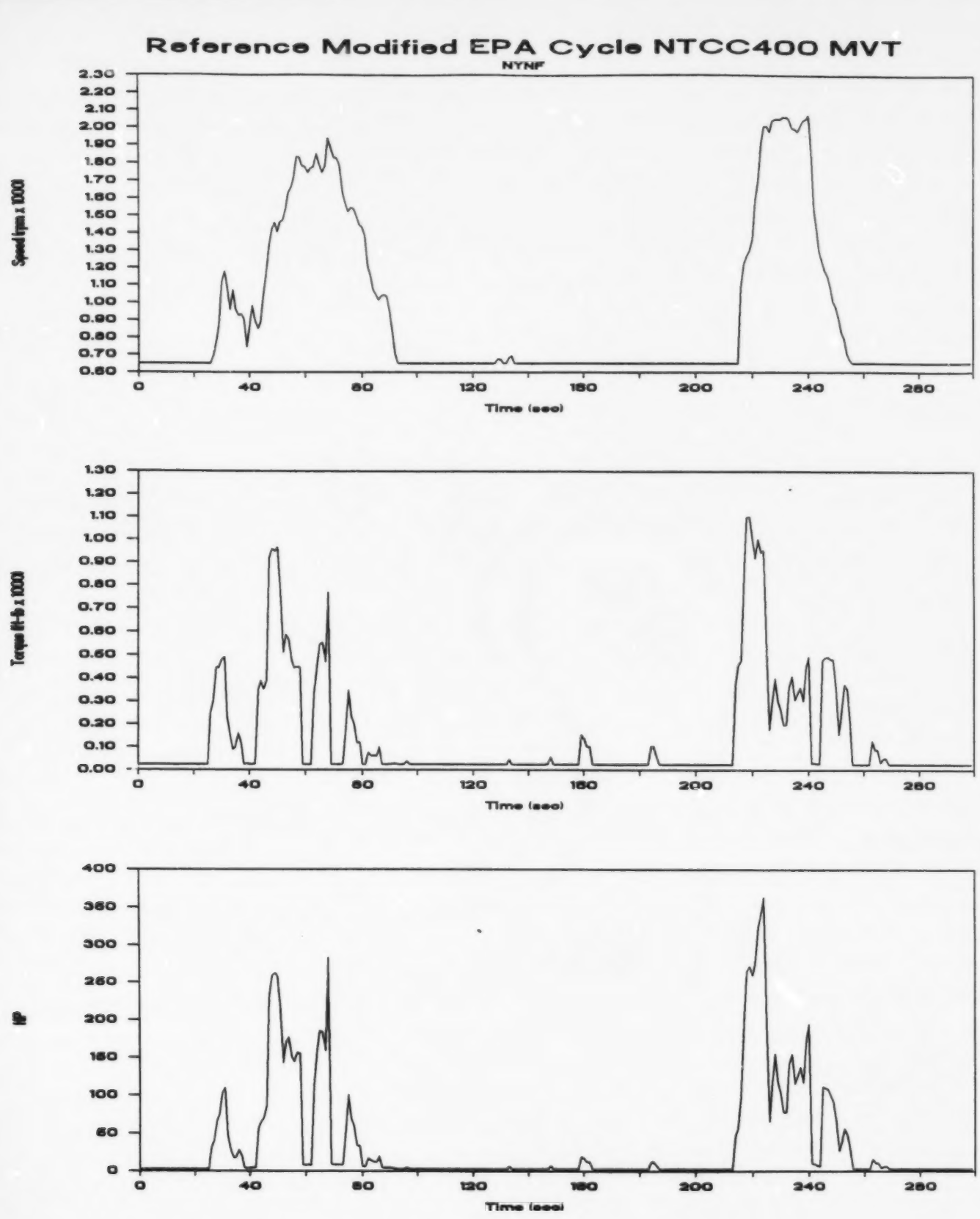

Reference Modified EPA Cycle NTCC400 MVT
NYNF
Speed (rpm x 1000)
2.30
2.20
2.10
2.00
1.90
1.80
1.70
1.60
1.50
1.40
1.30
1.20
1.10
1.00
0.90
0.80
0.70
0.60
0
40
80
120
160
200
240
280
Time (sec)
Torque (ft-lb x 1000)
1.30
1.20
1.10
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0
40
80
120
160
200
240
280
Time (sec)
HP
400
360
300
260
200
160
100
60
0
0
40
80
120
160
200
240
280
Time (sec)

FIGURE C.4.2.5

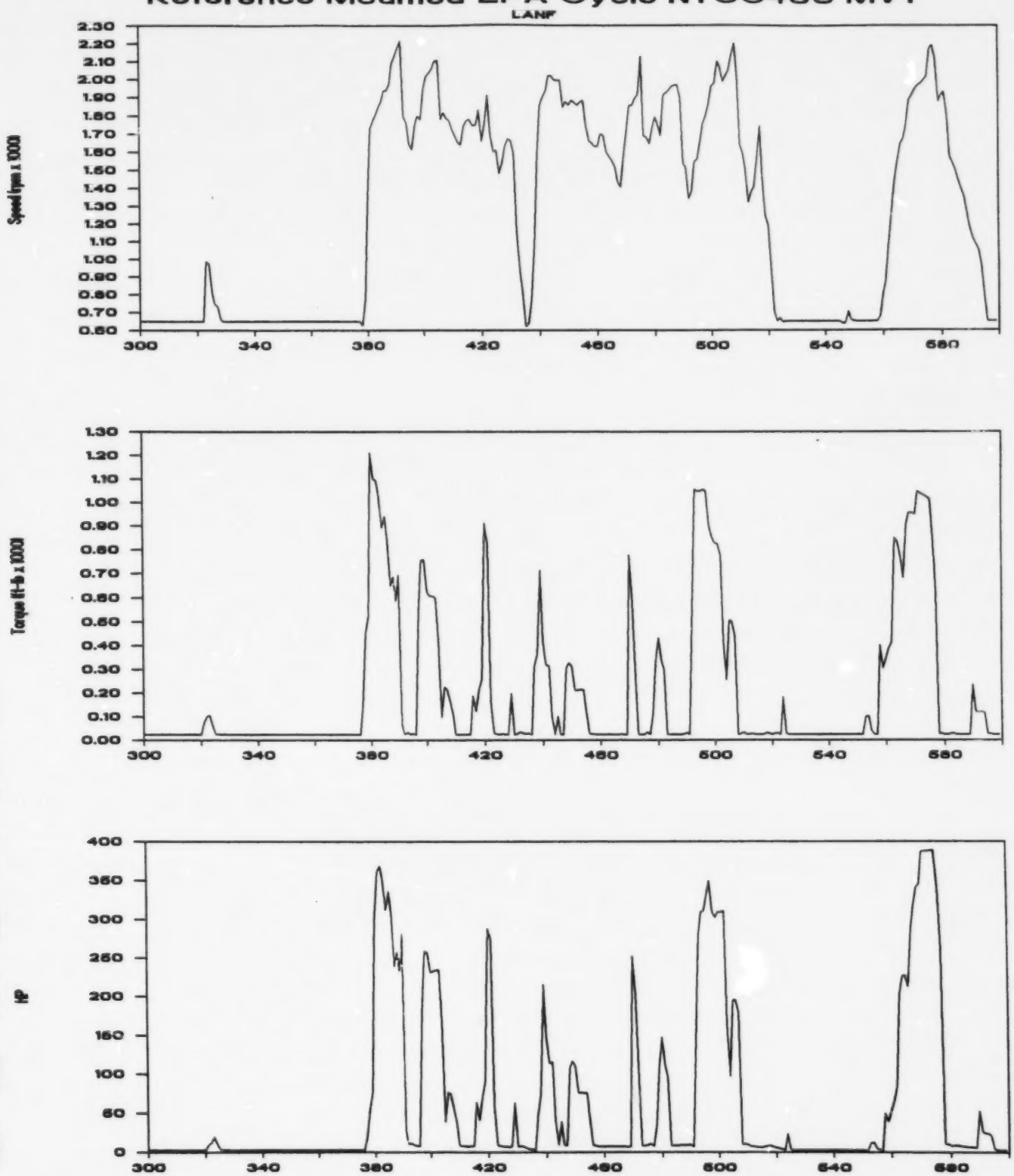

Reference Modified EPA Cycle NTCC400 MVT
LANF
Speed rpm x 1000
2.30
2.20
2.10
2.00
1.90
1.80
1.70
1.60
1.50
1.40
1.30
1.20
1.10
1.00
0.90
0.80
0.70
0.60
300
340
380
420
460
500
540
580
Torque ft-lb x 1000
1.30
1.20
1.10
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
300
340
380
420
460
500
540
580
HP
400
350
300
250
200
150
100
50
0
300
340
380
420
460
500
540
580

FIGURE C.4.2.6

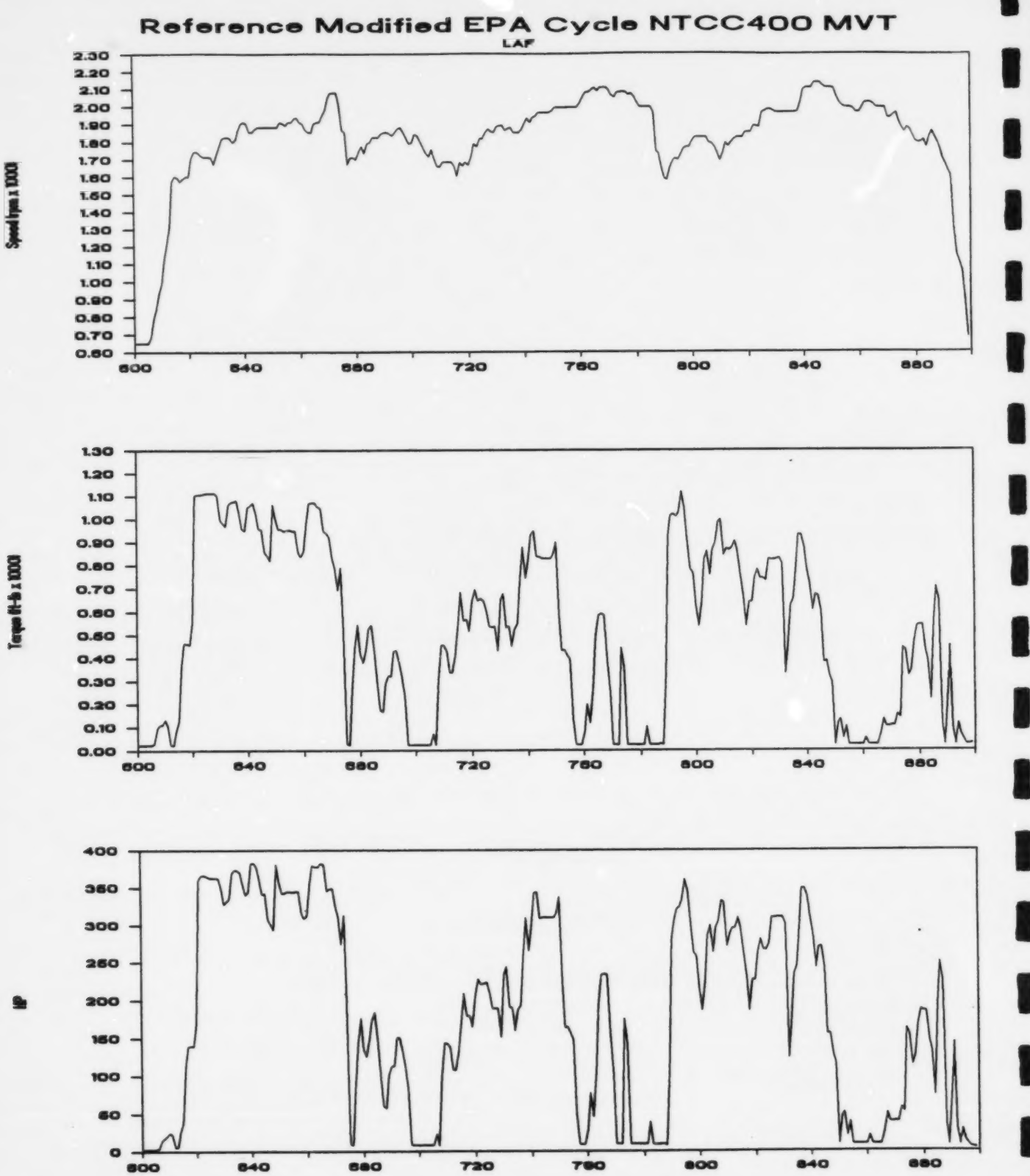

Reference Modified EPA Cycle NTCC400 MVT
LAF
Speed (rps x 1000)
2.30
2.20
2.10
2.00
1.90
1.80
1.70
1.60
1.50
1.40
1.30
1.20
1.10
1.00
0.90
0.80
0.70
0.60
600
640
680
720
760
800
840
880
Torque (ft-lb x 1000)
1.30
1.20
1.10
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
600
640
680
720
760
800
840
880
HP
400
350
300
250
200
150
100
50
0
600
640
680
720
760
800
840
880

FIGURE C.4.2.7

Modified EPA Cycle NTCC400 MVT
August 31, 1988

			EPA Limits Lower	Upper	
Speed Regression Output:					
Constant		57	-50	50	FAIL
Std Err of Y Est		160		100	FAIL
R Squared		0.92	0.97		FAIL
No. of Observations		1175			
Degrees of Freedom		1173			
X Coefficient(s)	0.93		0.97	1.03	FAIL
Std Err of Coef.	0.008				
Torque Regression Output:					
Constant		20	-15	15	FAIL
Std Err of Y Est		100		158	PASS
R Squared		0.90	0.88		PASS
No. of Observations		1175			
Degrees of Freedom		1173			
X Coefficient(s)	0.92		0.83	1.03	PASS
Std Err of Coef.	0.009				
HP Regression Output:					
Constant		4	-5	5	PASS
Std Err of Y Est		34		31.8	FAIL
R Squared		0.91	0.91		PASS
No. of Observations		1175			
Degrees of Freedom		1173			
X Coefficient(s)	0.96		0.89	1.03	PASS
Std Err of Coef.	0.009				
Ref Work	26.5				
Actual	26.8				
Ratio	1.01		0.85	1.05	PASS

TABLE C.4.2.4

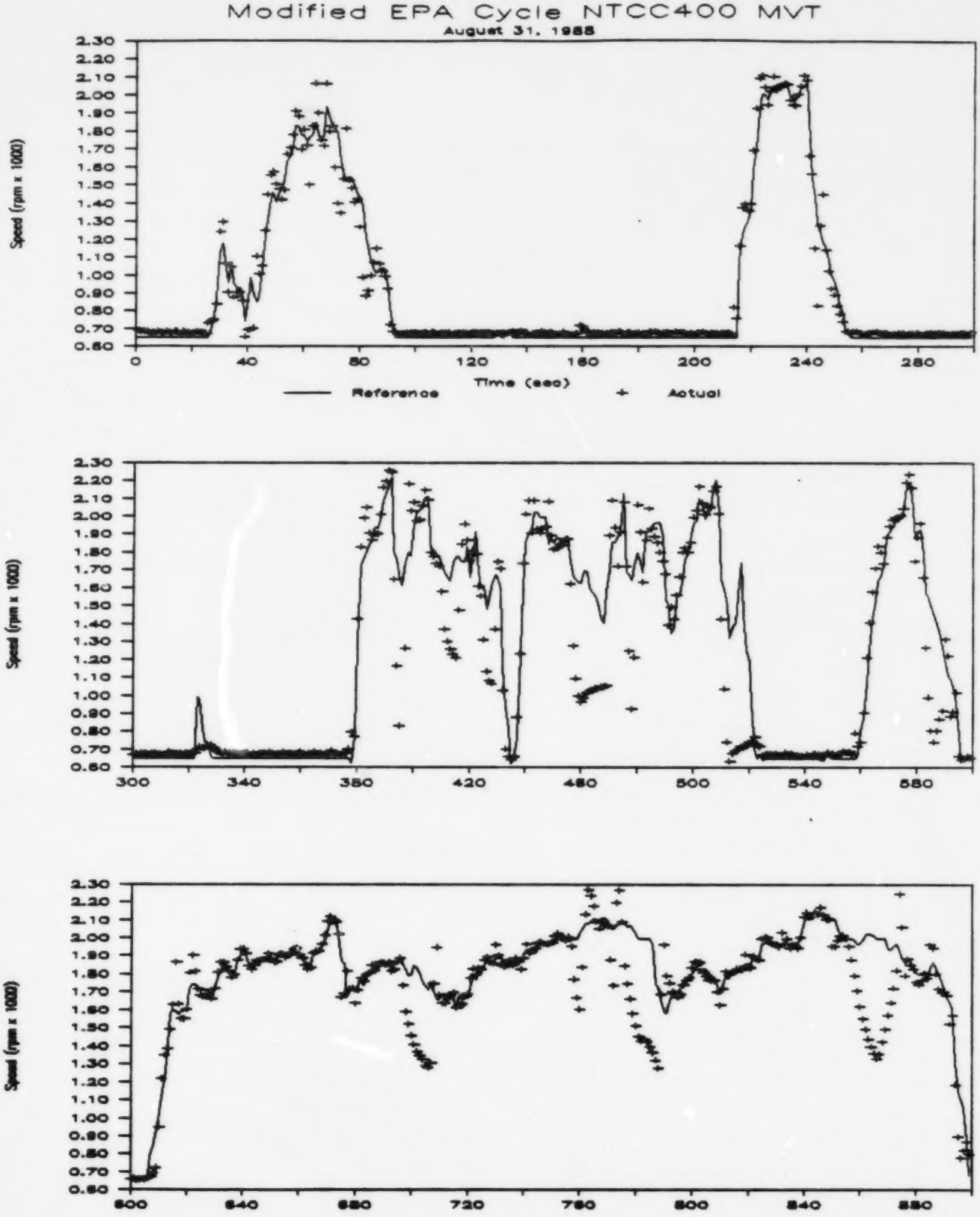

Modified EPA Cycle NTCC400 MVT
August 31, 1988
Speed (rpm x 1000)
Time (sec)
Reference
Actual

FIGURE C.4.2.8

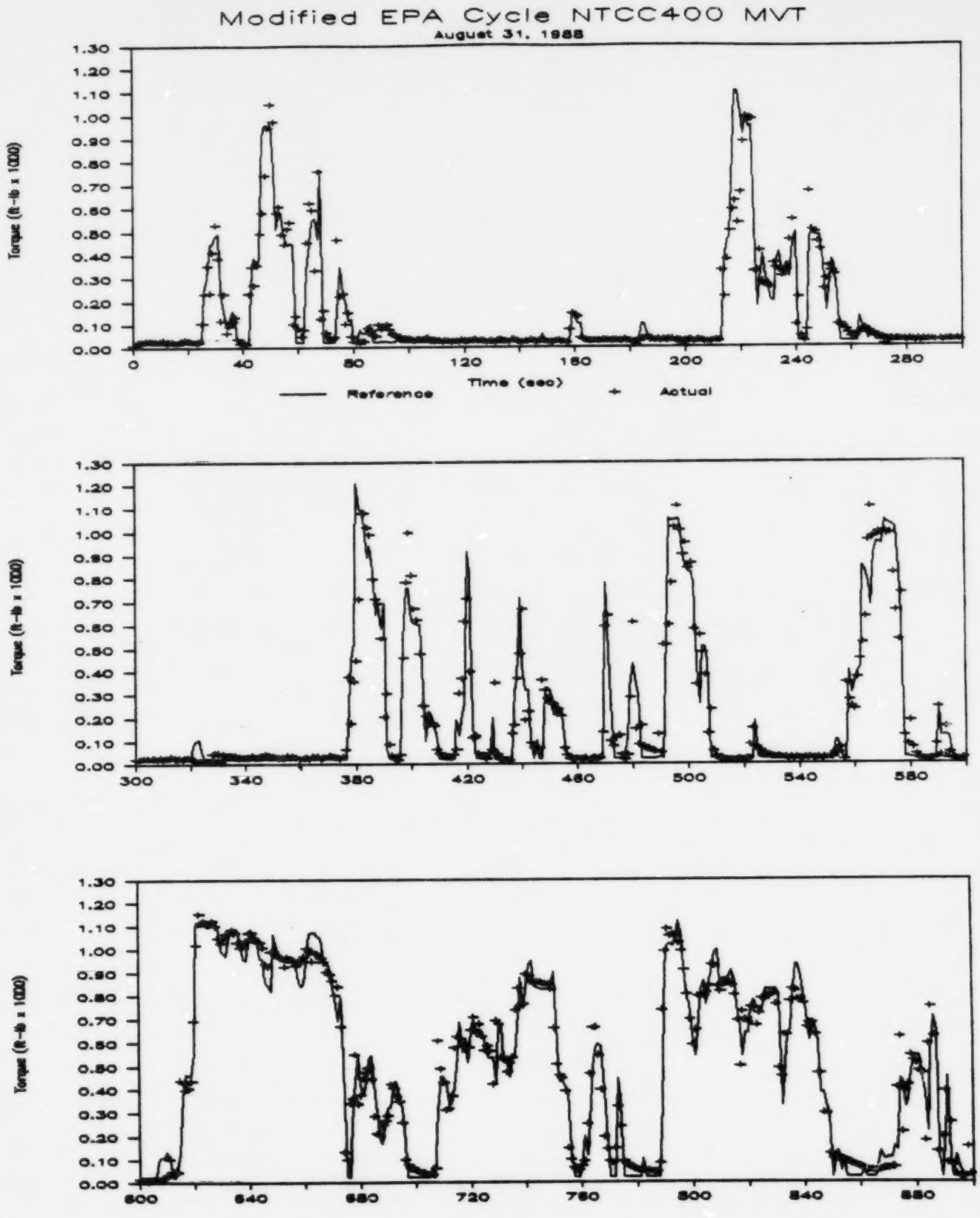

Modified EPA Cycle NTCC400 MVT
August 31, 1988
Torque (ft-lb x 1000)
1.30
1.20
1.10
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0
40
80
120
160
200
240
280
Time (sec)
Reference
Actual
300
340
380
420
460
500
540
580
600
640
680
720
760
800
840
880

FIGURE C.4.2.9

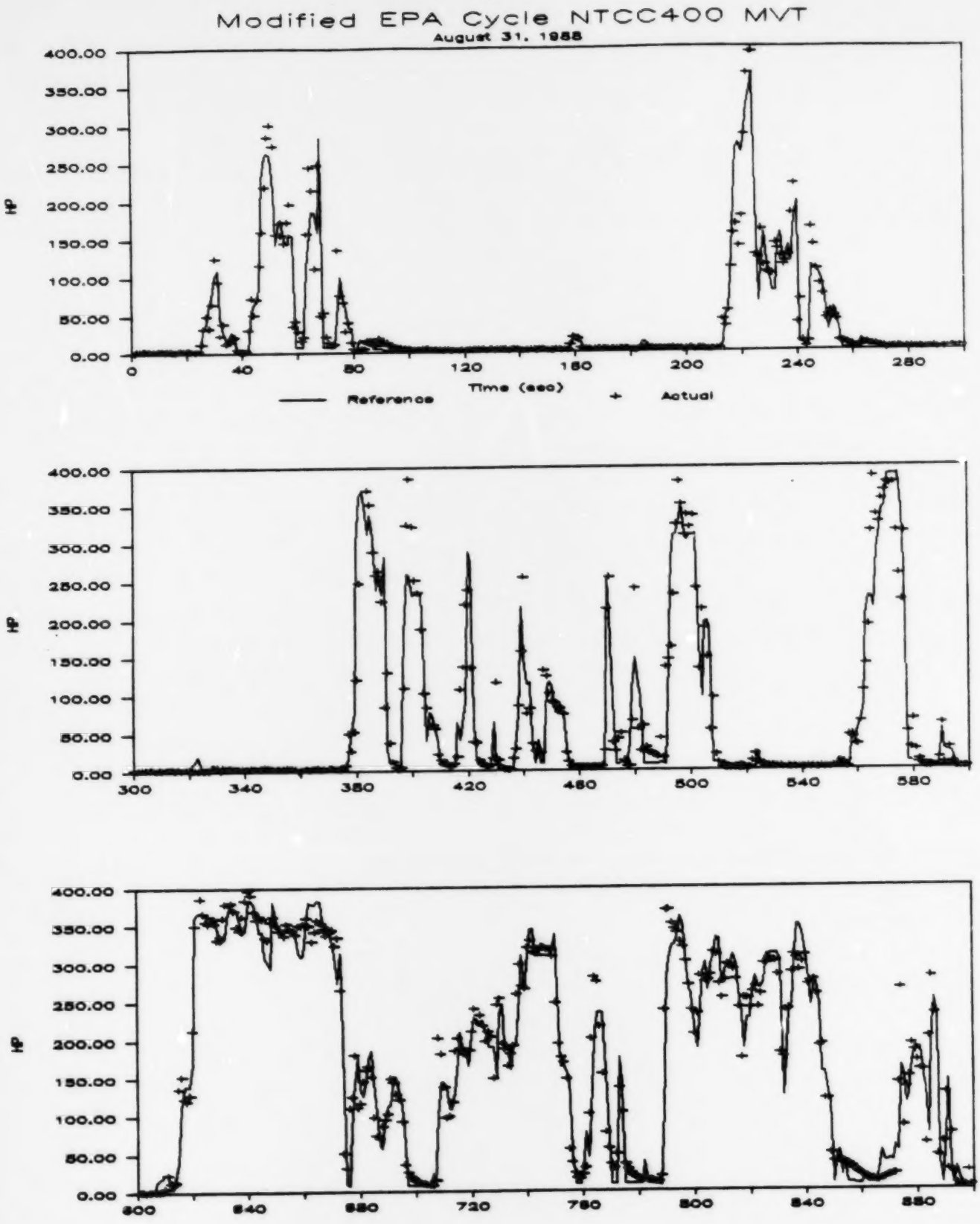


FIGURE C.4.2.10

2 POINT COMPARISON (After Dyno Rebuild)

Engine Model : NTCC 400
Engine ID No. : 10780756
Engine Hours : 650.5
Date : Sept 29,1988
Operator : Wayne Drummond
Project Manager : Kong Ha
Test Cell : 8

	Cummins	ORF	Difference	(%)	Cummins	ORF	Difference	(%)
Engine Speed (rpm)	2100	2100	0	0.0	1300	1300	0.0	0.0
Torque (ft-lbs)	966.62	993.7	27.1	2.8	1222.1	1207	-15.1	-1.2
Fuel Rate (lb/hr)	148.5	151.9	3.4	2.3	110.0	108.4	-1.6	-1.4
Brake Horse Power	386.2	397.3	11.1	2.9	302.3	298.8	-3.5	-1.2
BSFC (lb/bhp-hr)	0.385	0.382	-0.003	-0.7	0.364	0.363	-0.001	-0.3
Wet Barometer (in Hg)	29.481	29.62	0.139		29.483	29.62	0.137	
Vapor Pressure (in Hg)	0.70	0.35	-0.345		0.70	0.35	-0.35	
Wet Bulb (F)	----	62.6	----			62.6	----	
Dry Bulb (F)	----	55.4	----			55.4	----	
Intake Air (F)	77	77	0		79	79	0	
Intake Manifold (F)	190	191	1		174	174	0	
Engine Water In (F)	125	132	7		116	116	0	
Engine Water Out (F)	181	178	-3		178	176	-2	
Oil Pan (F)	225	191	-34		223	221	-2	
Fuel Temp at Pump (F)	103	97	-6		103	108	5	
Exhaust Stack (F)	892	994	102		1133	1178	45	
Test Cell (F)	104	95	-9		102	100	-2	
Intake Restriction (in H20)	-20.0	-23.1	-3.1		-4.9	-6.2	-1.3	
Intake Manifold (psi)	22.0	17	-5.0		13.3	10.0	-3.3	
Exhaust Back Press.(in Hg)	2.4	3.7	1.3		1.0	1.3	0.3	
Rail (psi)	173	180	7		112	112	0	
Oil Rifle Pressure (psi)	42	41.6	-0		35	30.2	-4	

Mass Fuel Consumption (Weight Scale)

Inital Wt 162.9 lbs
Final Wt. 147 lbs
15.9 lbs

Time 6 Min 16.80 Sec

Fuel Consumption 151.9 lb/hr

Mass Fuel Consumption (Weight Scale)

Inital Wt. 139.6 lbs
Final Wt. 127.9 lbs
11.7 lbs

Time 6 Min 28.60 Sec

Fuel Consumption 108.4 lb/hr

TABLE C.4.2.5
Performance Data NTCC 400 (September 29, 1988)

2 POINT COMPARISON (Before Dyno Rebuild)

Engine Model : NTCC 400
Engine ID No. : 10780756
Engine Hours :
Date : August 10,1988
Operator : Alex Baranovski
Project Manager : Kong Ha
Test Cell : 3

	Cummins	ORF	Difference	(%)	Cummins	ORF	Difference	(%)
Engine Speed (rpm)	2100	2096	-4	-0.2	1300	1302	2	0.2
Torque (ft-lbs)	966.62	985.8	19	2.0	1222.1	1207.3	-15	-1.2
Fuel Rate (lb/hr)	148.5	154.4	5.9	4.0	110.0	109.2	-0.8	-0.7
Brake Horse Power	386.2	394.7	8.5	2.2	302.3	298.5	-3.8	-1.2
BSFC (lb/bhp-hr)	0.385	0.391	0.007	1.7	0.364	0.366	0.002	0.6
Wet Barometer (in Hg)	29.481	29.54	0.059		29.483	29.54	0.057	
Vapor Pressure (in Hg)	0.70	0.339	-0.356		0.70	0.34	-0.361	
Wet Bulb (F)	----	64	----			64	----	
Dry Bulb (F)	----	80	----			80	----	
Intake Air (F)	77	84	7		79	90	11	
Intake Manifold (F)	190	191	1		174	174	0	
Engine Water In (F)	125	134	9		116	114	-2	
Engine Water Out (F)	181	178	-3		178	178	0	
Oil Pan (F)	225	205	-20		223	221	-2	
Fuel Temp at Pump (F)	103	96	-7		103	98	-5	
Exhaust Stack (F)	892	1016	124		1133	1199	66	
Test Cell (F)	104	112	8		102	124	22	
Intake Restriction (in H20)	-20.0	-21	-1		-4.9	-5.6	-1	
Intake Manifold (psi)	22.0	18.5	-4		13.3	13.3	-0	
Exhaust Back Press.(in Hg)	2.4	3.4	1		1.0	1.1	0	
Rail (psi)	173	180	7		112	112	0	
Oil Rifle Pressure (psi)	42	40.6	-1		35	30.8	-4	

Mass Fuel Consumption (Weight Scale)

Inital Wt 373.5 lbs
Final Wt. 352.1 lbs
21.4 lbs

Time 8 Min
19.00 Sec

Fuel Consumption 154.4 lb/hr

Mass Fuel Consumption (Weight Scale)

Inital Wt. 345 lbs
Final Wt. 329.8 lbs
15.2 lbs

Time 8 Min
21.00 Sec

Fuel Consumption 109.2 lb/hr

TABLE C.4.2.6

Performance Date NTCC 400 (August 10, 1988)

1-Jan-80 FILE : OPTRES

ycle Optimization

est Conducted on Oct 14, 1988

#	1	2	3	4	5	6	7	8
40	0.1		0.05				0.1	0.15
41	100						100	
42	-100						-100	
43								
44					-0.2	-0.5	-0.37	-0.37
45	0.25						0.25	
46	0.00037	0.00039	0.00037				0.00037	
47	0.00050			0.00048			0.00048	0.00052
48	700						700	
49	1		0.5		1	0.5	1	
50	25						25	
p	31	32	33	32	34	33	35	34
	79	89	83	79	88	87	85	95
	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.97
	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97
or	21	24	22	21	25	23	23	25
	93	96	94	93	95	94	94	104
	0.91	0.91	0.91	0.91	0.91	0.91	0.91	0.89
	0.92	0.91	0.91	0.92	0.91	0.91	0.91	0.9
p	5	6		5	5			
				Passed	Passed			

est Conducted on Oct 17, 1988

#	1	2	3	4	5	6	7	8	9
40	0.15		0.10	0.10	0.20	0.17	0.10	0.10	0.05
41	100	125	125	75		50	50	100	100
42	-100	-100	-100	-75		-50	-50	-100	-100
43									
44									
45	0.25								
46	0.00037								
47	0.00050							0.00048	0.00048
48	700							600	600
49	1								
50	25								
p	29	32	31	34	38	37	36	34	34
	85	85	91	89	85	79	86	69	89
	0.98	0.98	0.97	0.98	0.98	0.92	0.98	0.99	0.98
	0.98	0.97	0.97	0.97	0.97	0.97	0.98	0.97	0.98
or	24	24	27	26	26	25	26	26	25
	92	96	105	91	91	89	96	95	96
	0.92	0.91	0.89	0.92	0.92	0.92	0.91	0.91	0.91
	0.92	0.91	0.90	0.92	0.92	0.92	0.90	0.91	0.90
p	6								

est Conducted on Oct 18, 1988

#	1	2	3	4	5	6	7	8	9
40	0.05								
41	100								
42	-100								
43									
44				-0.3716					
45	0.25								
46	0.00037								
47	0.00048								
48	600	700							
49	0.5				1				
50	25								
p	26	25	21	27	31				
	66	67	58	86	75				
	0.99	0.99	0.99	0.98	0.98				
	0.98	0.99	0.99	0.98	0.98				
or	29	28	28	26	24				
	98	97	96	100	94				
	0.9	0.9	0.9	0.9	0.91				
	0.89	0.9	0.9	0.9	0.91				
p									

TABLE C.4.2.7

Control Coefficient

Optimization - NTCC 400

Modified EPA Cycle NTCC400 MVT
October 20,1988

			EPA Limits Lower	Upper	
Speed Regression Output:					
Constant		25	-50	50	PASS
Std Err of Y Est		65		100	PASS
R Squared		0.99	0.97		PASS
No. of Observations		1175			
Degrees of Freedom		1173			
X Coefficient(s)	0.98		0.97	1.03	PASS
Std Err of Coef.	0.003				
Torque Regression Output:					
Constant		34	-15	15	FAIL
Std Err of Y Est		99		158	PASS
R Squared		0.90	0.88		PASS
No. of Observations		1175			
Degrees of Freedom		1173			
X Coefficient(s)	0.88		0.83	1.03	PASS
Std Err of Coef.	0.009				
HP Regression Output:					
Constant		8	-5	5	FAIL
Std Err of Y Est		31		31.8	PASS
R Squared		0.92	0.91		PASS
No. of Observations		1175			
Degrees of Freedom		1173			
X Coefficient(s)	0.93		0.89	1.03	PASS
Std Err of Coef.	0.008				
Ref Work	26.5				
Actual	27.3				
Ratio	1.03		0.85	1.05	PASS

TABLE C.4.2.8

Cycle Regression Results - NTCC 400

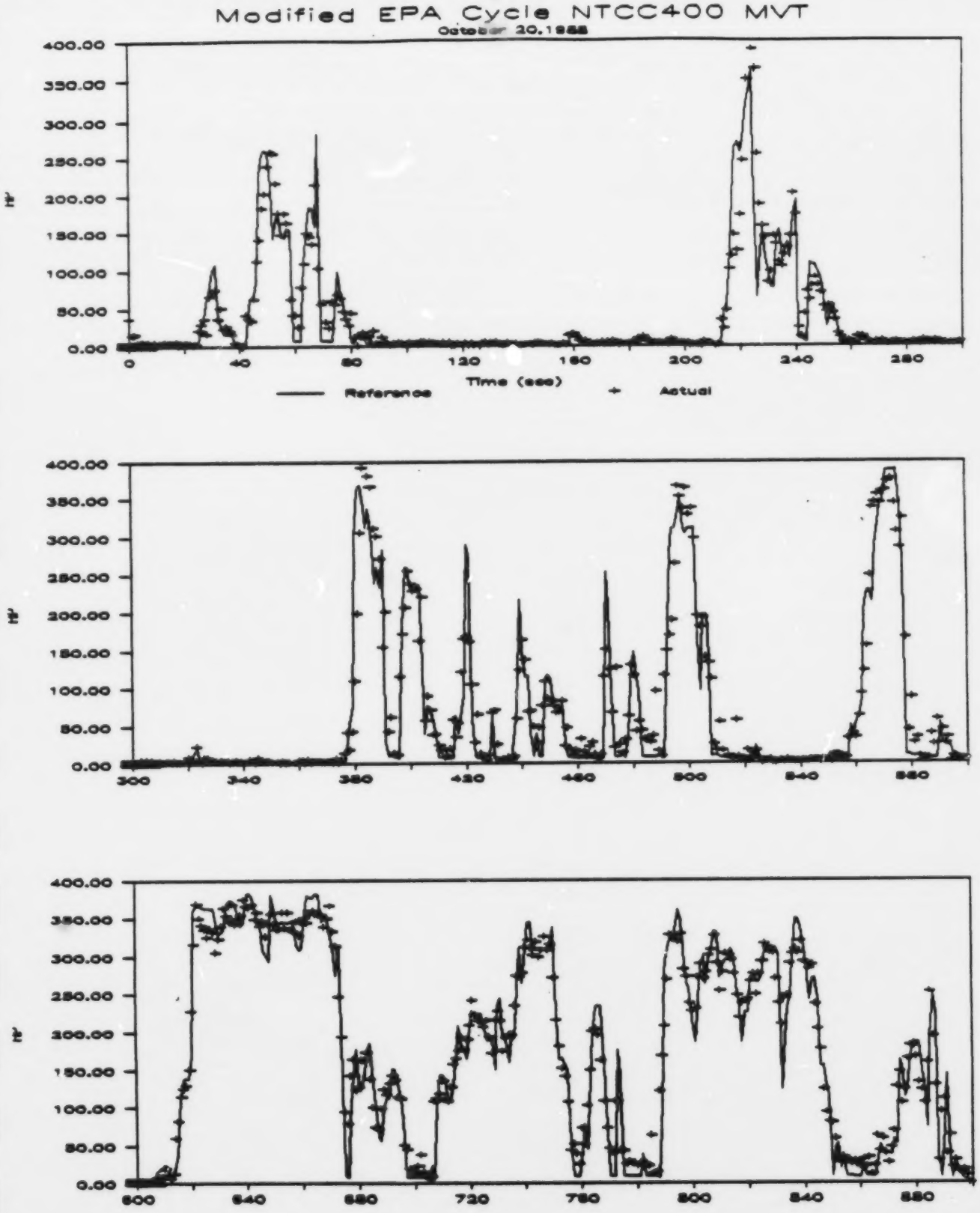


FIGURE C.4.2.11
NTCC 400 Modified Transient Cycle (0 - 300 sec.)

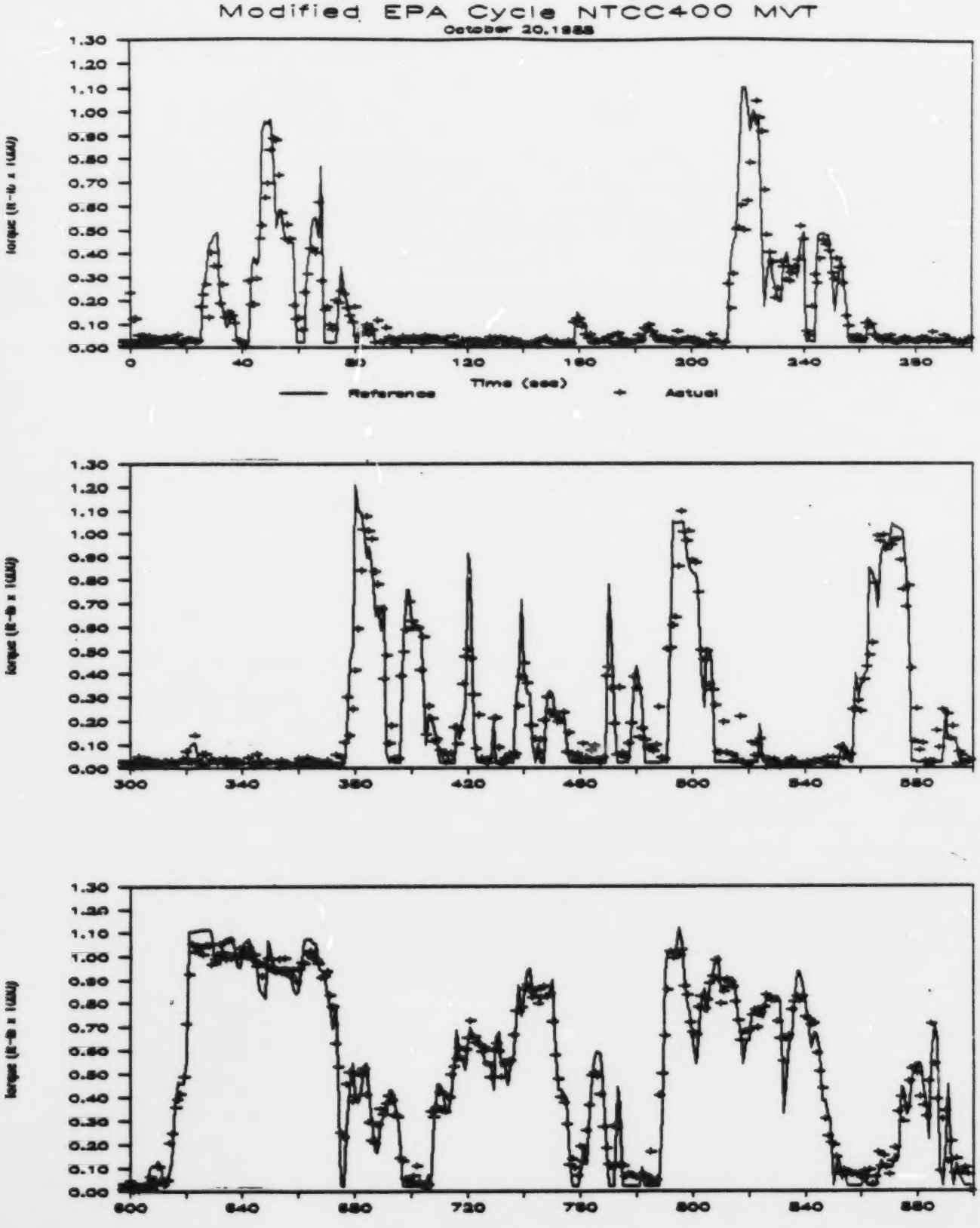


FIGURE C.4.2.12
NTCC 400 Modified Transient Cycle (30I - 600 sec)

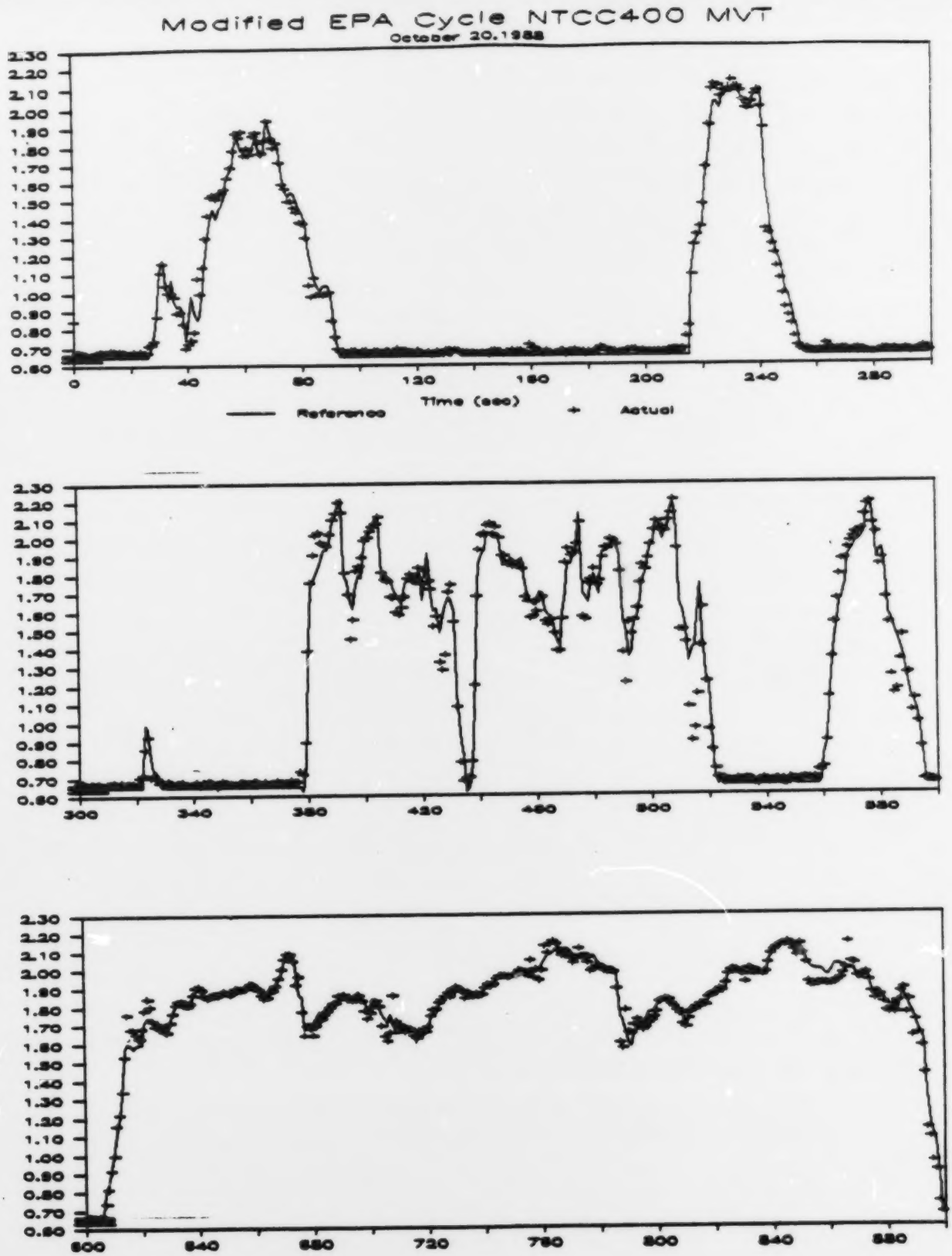


FIGURE C.4.2.13
NTCC 400 Modified Transient Cycle (601 - 900 sec)

Tables and Figures Referred to in "Section 4.3 - DDC Series 60" in Report.

TABLE C.4.3.1

2 POINT COMPARISON

Engine Model : DDC SERIES 60
Engine ID No.: 6R-544
Engine Hours : 1058
Date : JUNE 9 88
Operator : C.L. , B.M.
Project Manager : K.H.
Test Cell :

	DDC	SRF	DIFFERENCE	%	DDC	SRF	DIFFERENCE	%
Engine Speed (rpm)	1800	1803	3	0.2	1200	1215	15	1.3
Torque (ft-lbs)	918	907	-11	-1.2	1198	1178	-20	-1.7
Fuel Rate (lb/hr)	104.3	102.7	-1.6	-1.5	91.7	90	-1.7	-1.9
Brake Horse Power	314.6	308	-6.6	-2.1	274.0	278	4	1.5
BSFC (lb/bhp-hr)	0.332	0.333	0.001	0.3	0.335	0.323	-0.012	-3.6
Barometric Pr. (in Hg)	29.31	29.45	0.14		29.31	29.45	0.14	
Vapor Pressure (in Hg)	0.50	0.4	-0.1		0.51	0.4	-0.11	
Wet Bulb (F)		58				58		
Dry Bulb (F)		66				66		
Intake Air (F)	79.3	72	-7.3		77.8	73	-4.9	
Intercooler in (F)	290	275	-15		266	255	-11	
Intercooler out (F)	109	100	-9		97	85	-12	
Engine Water In (F)		167				162		
Engine Water Out (F)	183	188	5		183	189	6	
Oil Pan (F)	223	215	-8		219	219	0	
Fuel Temp at Pump (F)	101	97	-4		100	99	-1	
Exhaust Stack (F)		813				968		
Test Cell (F)		94				96		
Intake Restriction (in H2O)	-20.5	-19.03	1.42		-8.4	-8.68	-0.28	
Intercooler in ("Hg)	40.2	38.71	-1.49		35.6	33.69	-1.91	
Intercooler out ("Hg)	38.4	36.72	-1.68		34.2	33.04	-1.16	
Intercooler Diff(1.8-1.9"Hg)	1.8	1.99	0.19		1.5	0.65	-0.85	
Exhaust Back Press.(in Hg)	3.01	3.15	0.14		1.5	1.67	0.19	
Oil Rifle Pressure (psi)	51.3	52.6	1.3		44.7	44.6	-0.1	

FIGURE C 4.3.1: Torque Curve Comparison (DDC Engine)

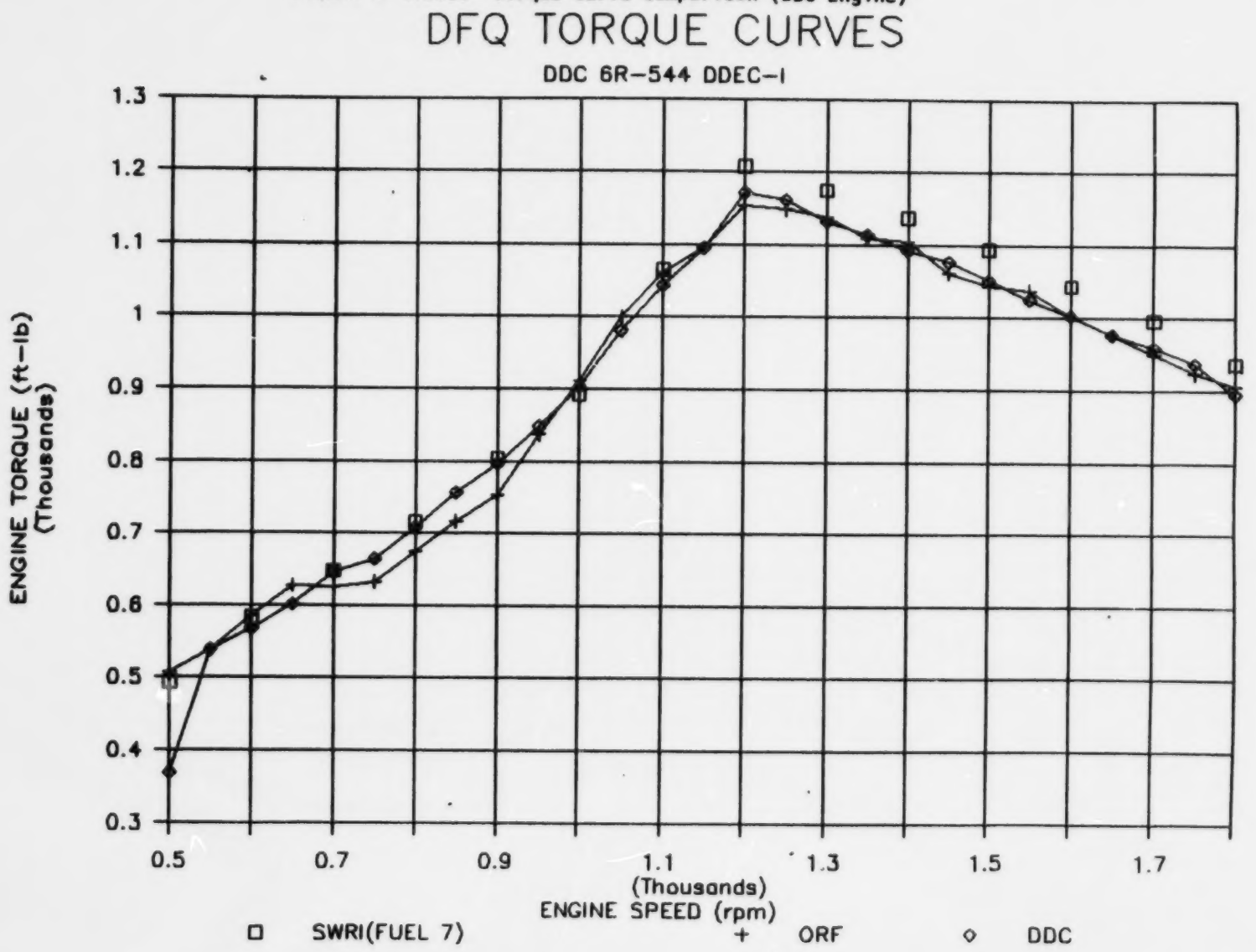


TABLE C.4.3.2

MANUAL TORQUE CURVE (DDC Engine vs DDC)

Engine Model : SERIES 60
Engine ID No. : 6R-544
Engine Hours : 1058
Date : JUNE 9/88
Operator : C.L. B.M.
Project Manager : Kong Ha
Test Cell: 7

Barometric Pressure ("Hg) :	29.46	Intake Air (F) :	75
Wet Bulb Temp (F) :	58	Relative Humidity (%) :	------
Dry Bulb Temp. (F) :	66		
		Maximum Torque (lb-ft) :	1155
Maximum Torque (lb-ft)	905	Horsepower (BHP) :	2[illegible]
Rated Power (Hp) :	309	Engine Speed :	1215
Engine Speed (rpm) :	1804	Fuel Consumption (lb/hr) :	90
Fuel Consumption (lb/hr) :	103.2	Curb Idle Speed (rpm) :	500
Inlet Depress.("H2O) :	-18.72	Governed Speed (rpm) :	1840
Exhaust B.P. ("Hg) :	3.11	Max EPA Cycle Speed (rpm):	------
Map Technique Used :	MANUAL,SPEED CONTROL,ORF BASELINE FUEL FROM DRUM		

DDC Reference Torque Curve — ORF JUNE 9,1988

Speed (rpm)	Torque (lb-ft)	BHP	Torque (lb-ft)	Difference (lb-ft)	Difference (%)	BHP	Difference hp	Difference (%)
500	369	35	507	138	27	48	13	27
550	538	56	539	1	0	56	0	0
600	568	65	586	18	3	67	2	3
650	601	74	627	26	4	78	3	4
700	645	86	625	-20	-3	83	-3	-3
750	664	95	632	-32	-5	90	-5	-5
800	708	108	675	-33	-5	103	-5	-5
850	756	122	717	-39	-5	116	-6	-5
900	797	137	753	-44	-6	129	-7	-6
950	848	153	837	-11	-1	151	-2	-1
1000	904	172	911	7	1	173	1	1
1050	981	196	1001	20	2	200	4	2
1100	1044	219	1062	18	2	222	4	2
1150	1095	240	1096	1	0	240	0	0
1200	1173	268	1154			264		
1250	1162	276	1149	-13	-1	273	-3	-1
1300	1132	280	1138	6	1	282	1	1
1350	1114	286	1110	-4	-0	285	-1	-0
1400	1092	291	1104	12	1	294	3	1
1450	1077	297	1061	-16	-1	293	-4	-1
1500	1051	300	1044	-7	-1	298	-2	-1
1550	1025	303	1038	13	1	306	4	1
1600	1003	306	1002	-1	-0	305	-0	-0
1650	977	307	977	-0	-0	307	-0	-0
1700	959	310	950	-9	-1	308	-3	-1
1750	937	312	924	-13	-1	308	-4	-1
1800	896	307	906	10	1	311	3	1
MAXIMUM	1173	312	1154			311		

TABLE C.4.3.3
MANUAL TORQUE CURVE (DDC Engine vs SwRI)

Engine Model : SERIES 60
Engine ID No. : 6R-544
Engine Hours : 1058
Date : JUNE 9/88
Operator : C.L. B.M.
Project Manager : Kong Ha
Test Cell: 7

Barometric Pressure ("Hg) :	29.46	Intake Air (F) :	75
Wet Bulb Temp (F) :	58	Relative Humidity (%) :	------
Dry Bulb Temp. (F) :	66		
		Maximum Torque (lb-ft) :	1158
Maximum Torque (lb-ft)	905	Horsepower (BHP) :	2??
Rated Power (Hp) :	309	Engine Speed :	1219
Engine Speed (rpm) :	1804	Fuel Consumption (lb/hr) :	90
Fuel Consumption (lb/hr) :	103.2	Curb Idle Speed (rpm) :	500
Inlet Depress.("H2O) :	-18.72	Governed Speed (rpm) :	1940
Exhaust B.P. ("Hg) :	3.11	Max EPA Cycle Speed (rpm):	------

Map Technique Used : MANUAL,SPEED CONTROL,ORF BASELINE FUEL FROM DRUM

SWRI (FUEL 7) ORF
Reference Torque Curve JUNE 9,1988

Speed (rpm)	Torque (lb-ft)	BHP	Torque (lb-ft)	Difference (lb-ft)	(%)	BHP	Difference hp	(%)
500	494	47	507	13	3	48	1	3
550			539			56		
600	583	67	586	3	1	67	0	1
650			627			78		
700	648	86	625	-23	-4	83	-3	-4
750			632			90		
800	716	109	675	-41	-6	103	-6	-6
850			717			116		
900	804	138	753	-51	-7	129	-9	-7
950			837			151		
1000	893	170	911	18	2	173	3	2
1050			1001			200		
1100	1066	223	1062	-4	-0	222	-1	-0
1150			1096			240		
1200	1208	276	1154	-54	-5	264	-12	-5
1250			1149			273		
1300	1175	291	1138	-37	-3	282	-9	-3
1350			1110			285		
1400	1137	303	1104	-33	-3	294	-9	-3
1450			1061			293		
1500	1094	312	1044	-50	-5	298	-14	-5
1550			1038			306		
1600	1044	318	1002	-42	-4	305	-13	-4
1650			977			307		
1700	997	323	950	-47	-5	308	-15	-5
1750			924			308		
1800	937	321	906	-31	-3	311	-11	-3
MAXIMUM	1208	323	1154			311		

01-Jan-80 FILE : EPACOM

Modified EPA Cycle DDC 6R-544
JUNE 22, 1988

			EPA Limits Lower	Upper	
Speed Regression Output:					
Constant		25	-50	50	PASS
Std Err of Y Est		61		100	PASS
R Squared		0.99	0.97		PASS
No. of Observations		1175			
Degrees of Freedom		1173			
X Coefficient(s)	1.01		0.97	1.03	PASS
Std Err of Coef.	0.004				
Torque Regression Output:					
Constant		33	-15	15	FAIL
Std Err of Y Est		92		156	PASS
R Squared		0.91	0.88		PASS
No. of Observations		1175			
Degrees of Freedom		1173			
X Coefficient(s)	0.88		0.83	1.03	PASS
Std Err of Coef.	0.008				
HP Regression Output:					
Constant		7	-5	5	FAIL
Std Err of Y Est		25		24.9	PASS
R Squared		0.93	0.91		PASS
No. of Observations		1175			
Degrees of Freedom		1173			
X Coefficient(s)	0.96		0.89	1.03	PASS
Std Err of Coef.	0.008				
Ref Work	20.9				
Actual	22.3				
Ratio	1.07		0.85	1.05	FAIL

TABLE C.4.3.4

Modified EPA Cycle DDC 6R-544
AUGUST 22, 1988

			EPA Limits Lower	Upper	
Speed Regression Output:					
Constant		-6	-50	50	PASS
Std Err of Y Est		79		100	PASS
R Squared		0.97	0.97		PASS
No. of Observations		1175			
Degrees of Freedom		1173			
X Coefficient(s)	0.99		0.97	1.03	PASS
Std Err of Coef.	0.005				
Torque Regression Output:					
Constant		15	-15	15	PASS
Std Err of Y Est		71		156	PASS
R Squared		0.95	0.88		PASS
No. of Observations		1175			
Degrees of Freedom		1173			
X Coefficient(s)	0.93		0.83	1.03	PASS
Std Err of Coef.	0.006				
HP Regression Output:					
Constant		4	-5	5	PASS
Std Err of Y Est		19		24.9	PASS
R Squared		0.95	0.91		PASS
No. of Observations		1175			
Degrees of Freedom		1173			
X Coefficient(s)	0.95		0.89	1.03	PASS
Std Err of Coef.	0.006				
Ref Work	20.9				
Actual	20.9				
Ratio	1.00		0.85	1.05	PASS

TABLE C.4.3.5

TABLE C.4.3.6 Fuel Performance Comparison.

STEADY STATE FUEL TO FUEL PERFORMANCE COMPARISON
(DDC SERIES 60 ENGINE)

	DDC OCT 87	FUEL A	FUEL B	FUEL C	FUEL D	FUEL E	FUEL F (AVG)
RPM	1800	1801	1798	1801	1800	1800	1800
Torque (ft.lbs)	918	937	970	983	955	959	901
Fuel Rate (lbs/hr)	104.3	104.2	109.4	108.2	109.6	108.6	102.5
Horse Power	314.6	321.3	332.1	337.1	327.3	328.7	307.2
BSFC (lbs/bhp-hr)	0.332	0.324	0.329	0.321	0.335	0.33	0.333
RPM	1200	1268	1337	1337	1299	1281	1220
Torque (ft.lbs)	1198	1172	1172	1192	1176	1187	1157
Fuel Rate (lbs/hr)	91.7	92.5	98.3	96.7	98.1	96.3	89.9
Horse Power	274	283	298.4	303.4	290.9	289.5	270.2
BSFC (lbs/bhp-hr)	0.335	0.327	0.329	0.319	0.337	0.333	0.333

REFERENCE FUEL F
ORTECH DATA

MAY 31	JUN 9	JULY 21	AUG 9	SEPT 12	NOV 28
1800	1803	1800	1799	1798	1798
900	907	910	902	894	891
	102.7	103	103.5	101.5	101.6
310	308	308	309	306	305
	0.333	0.334	0.335	0.332	0.333
1205	1215	1230	1222	1227	1207
1150	1178	1150	1152	1149	1158
	90	90.2	90.4	89.4	89.6
268	278	271	268	268	266
	0.323	0.333	0.337	0.333	0.337

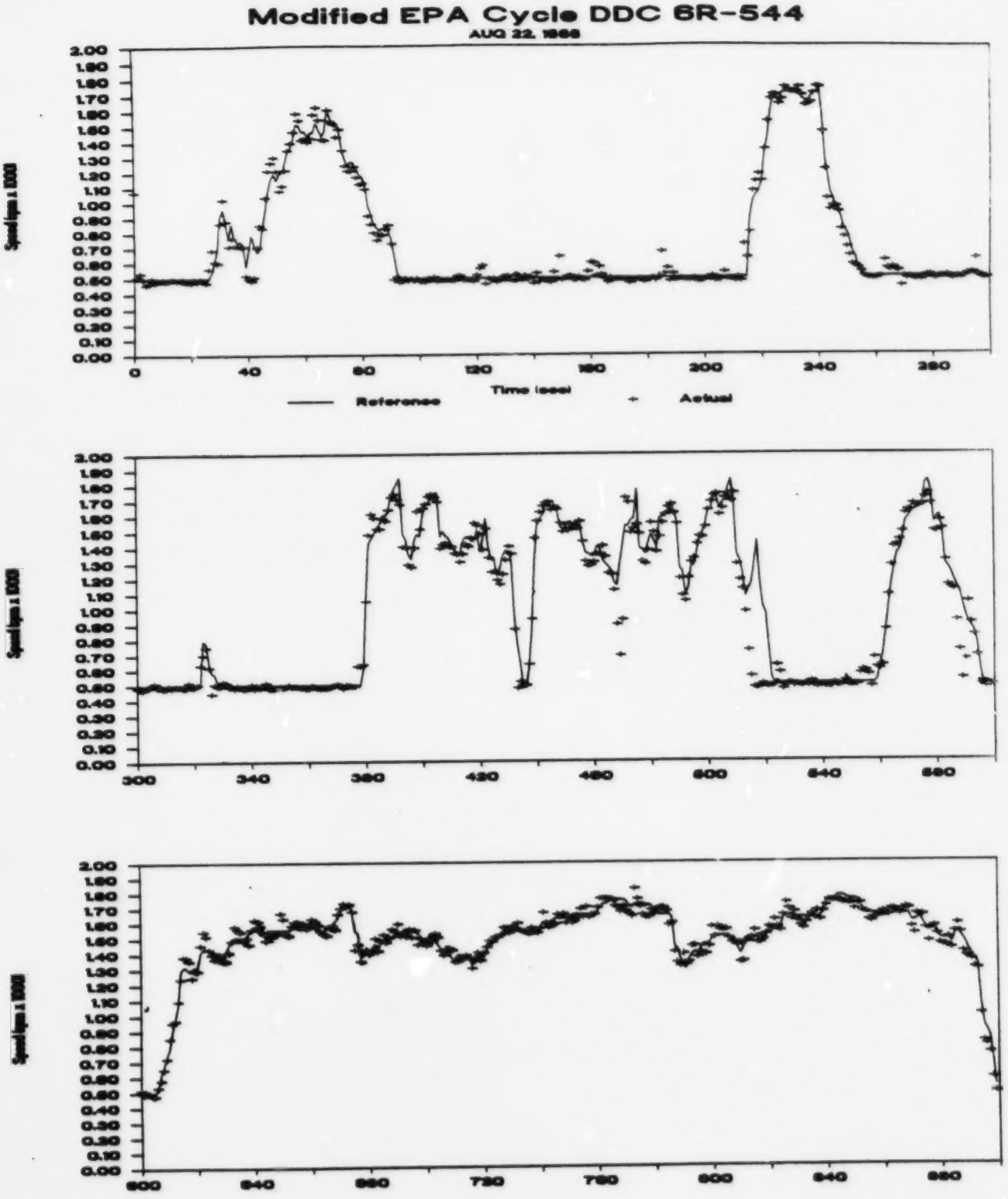
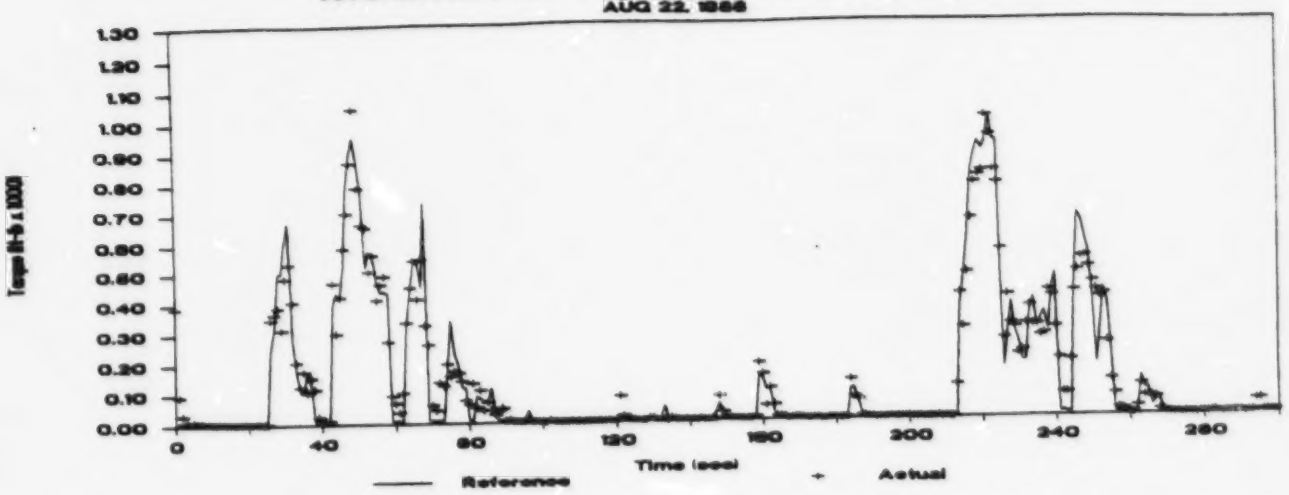
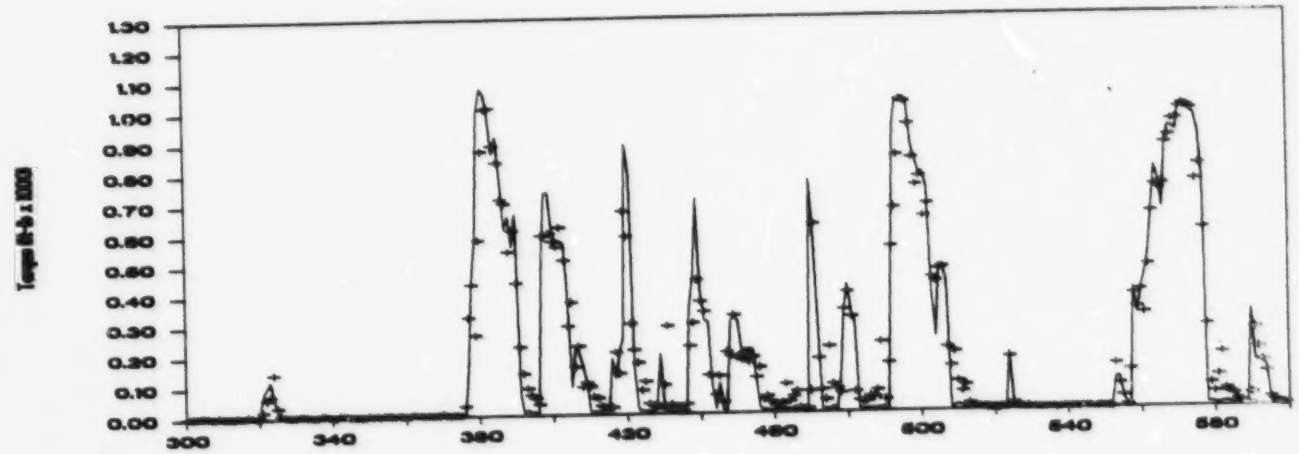

Modified EPA Cycle DDC 6R-544
AUG 22, 1988
Time (sec)
Reference
Actual

FIGURE C.4.3.2

Modified EPA Cycle DDC 6R-544

AUG 22, 1986





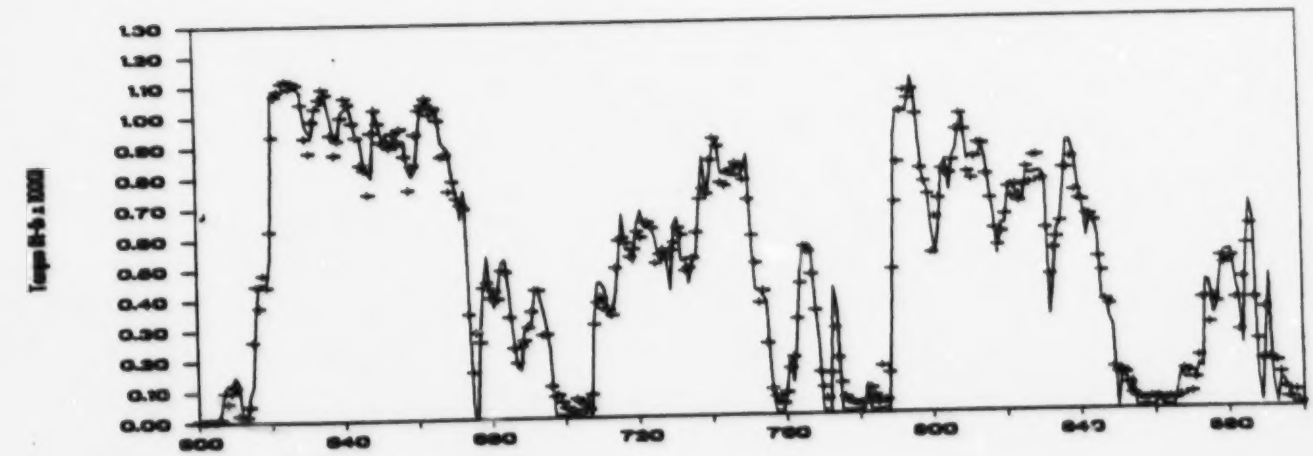


TABLE C.4.3.3

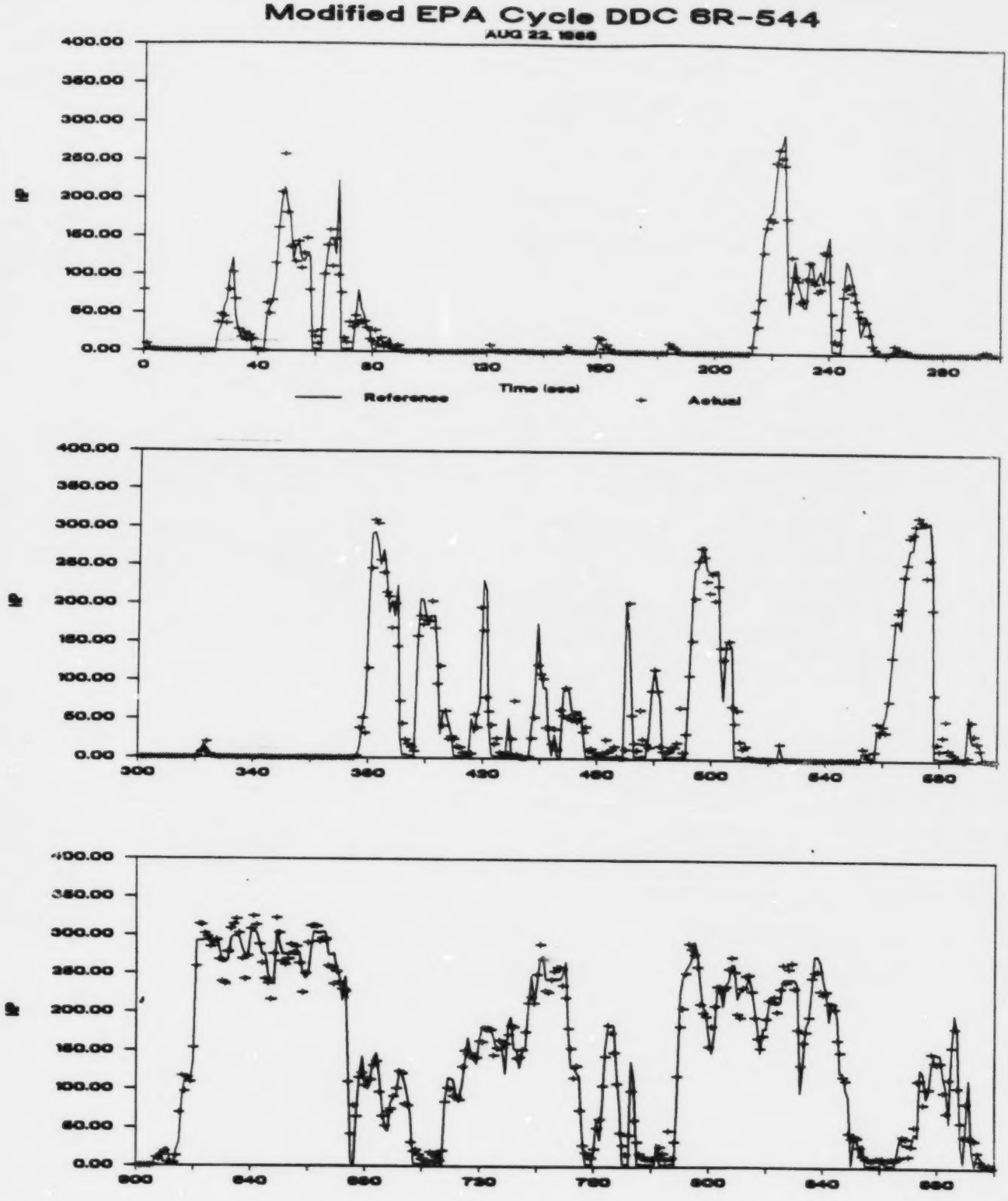

Modified EPA Cycle DDC 6R-544
AUG 22, 1988
400.00
360.00
300.00
250.00
200.00
150.00
100.00
50.00
0.00
0
40
80
120
160
200
240
280
Time (sec)
Reference
Actual
300
340
360
420
480
600
640
680
800
840
880
720
760
800
840
880

FIGURE C.4.3.4

APPENDIX D: Calibration Procedures, Tables & Figures.

TABLE C.4.3.6 Fuel Performance Comparison.

STEADY STATE FUEL TO FUEL PERFORMANCE COMPARISON
(DDC SERIES 60 ENGINE)

	DDC OCT 87	FUEL A	FUEL B	FUEL C	FUEL D	FUEL E	FUEL F (AVG)
RPM	1800	1801	1798	1801	1800	1900	1800
Torque (ft.lbs)	918	937	970	983	955	959	901
Fuel Rate (lbs/hr)	104.3	104.2	109.4	108.2	109.6	108.6	102.5
Horse Power	314.6	321.3	332.1	337.1	327.3	328.7	307.2
BSFC (lbs/bhp-hr)	0.332	0.324	0.329	0.321	0.335	0.33	0.333
RPM	1200	1268	1337	1337	1299	1281	1220
Torque (ft.lbs)	1198	1172	1172	1192	1176	1187	1157
Fuel Rate (lbs/hr)	91.7	92.5	98.3	96.7	98.1	96.3	89.9
Horse Power	274	283	298.4	303.4	290.9	289.5	270.2
BSFC (lbs/bhp-hr)	0.335	0.327	0.329	0.319	0.337	0.333	0.333

REFERENCE FUEL F
ORTECH DATA

MAY 31	JUN 9	JULY 21	AUG 9	SEPT 12	NOV 28
1800	1803	1800	1799	1798	1798
900	907	910	902	894	891
	102.7	103	103.5	101.5	101.6
310	308	308	309	306	305
	0.333	0.334	0.335	0.332	0.333
1205	1215	1230	1222	1227	1207
1158	1178	1150	1152	1149	1158
	90	90.2	90.4	89.4	89.6
268	278	271	268	268	266
	0.323	0.333	0.337	0.333	0.337

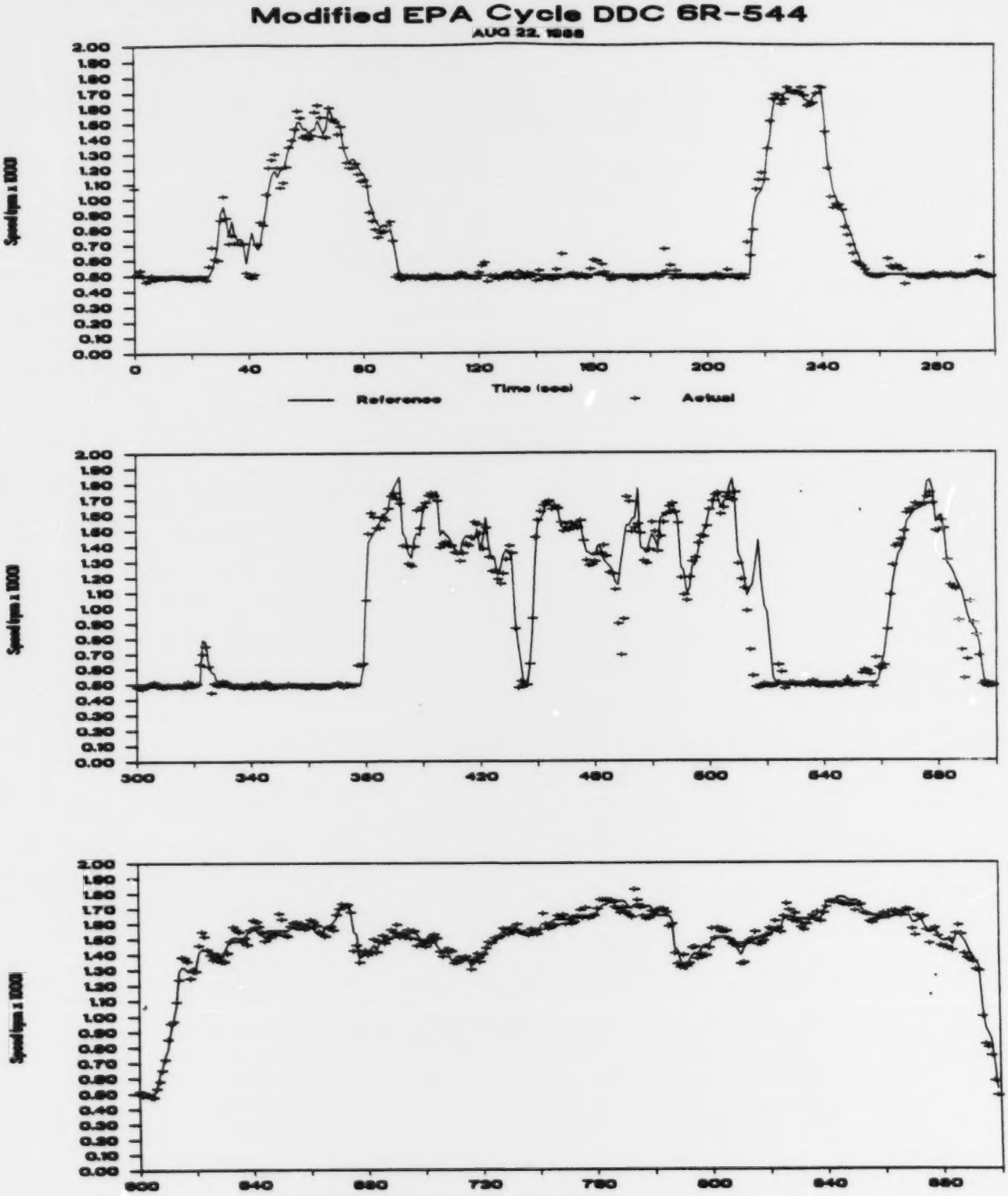

Modified EPA Cycle DDC 6R-544
AUG 22, 1988
Speed rpm x 1000
Time (sec)
Reference
Actual

FIGURE C.4.3.2

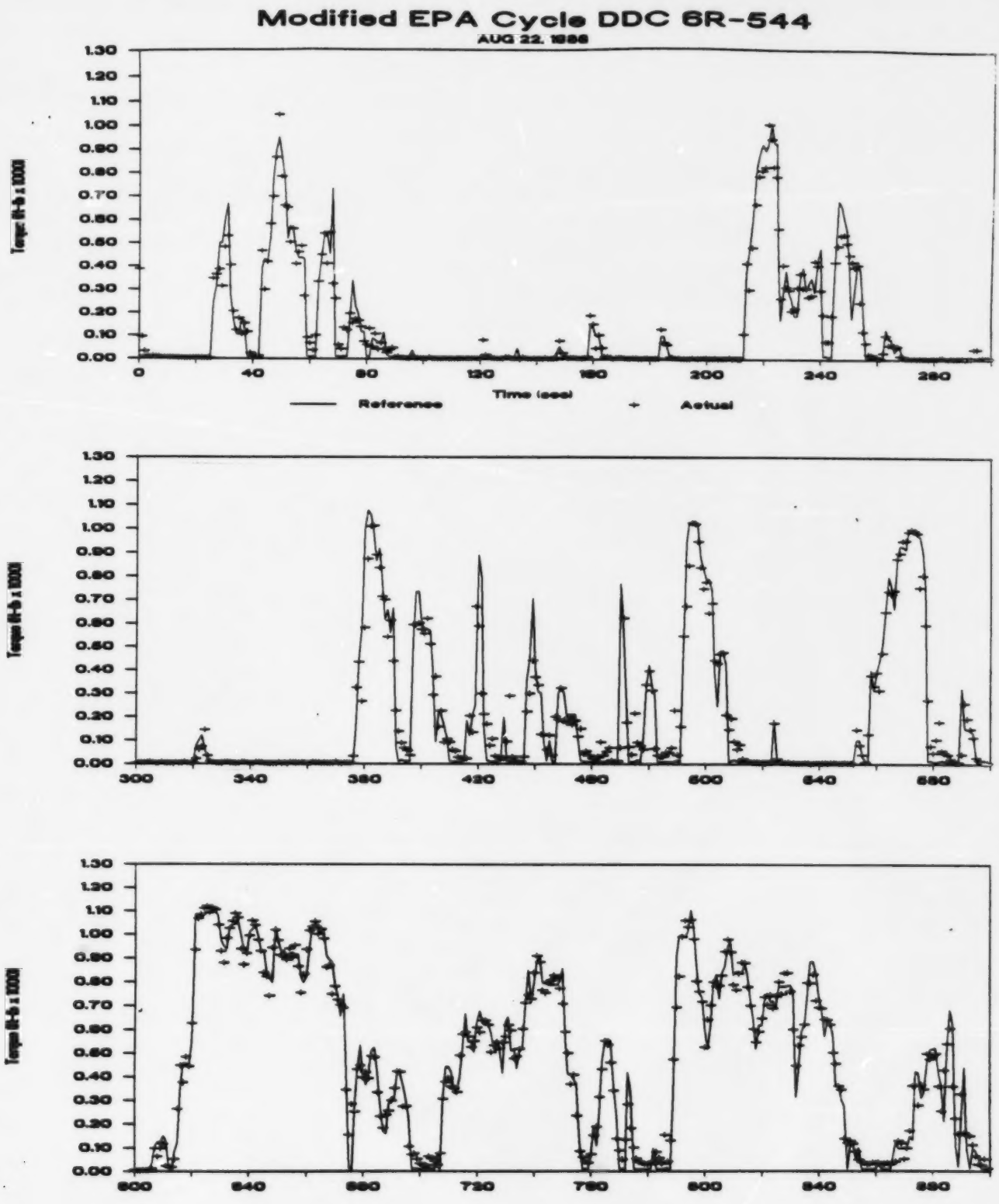

Modified EPA Cycle DDC 6R-544
AUG 22, 1986
Torque (ft-lb x 1000)
Time (sec)
Reference
Actual

TABLE C.4.3.3

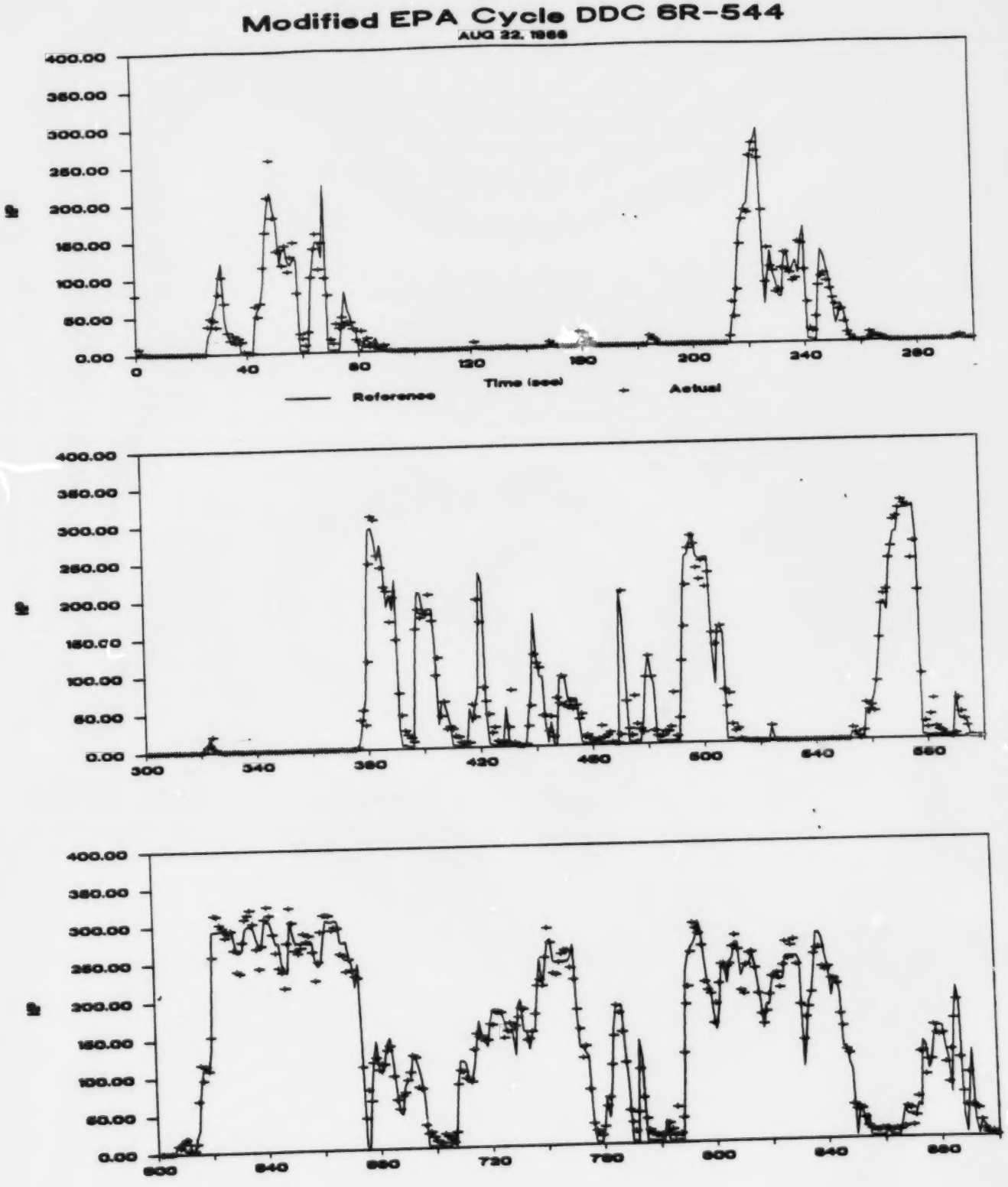

Modified EPA Cycle DDC 6R-544
AUG 22, 1988
400.00
360.00
300.00
280.00
200.00
160.00
100.00
60.00
0.00
0
40
80
120
160
200
240
280
Time (sec)
Reference
Actual
300
340
380
420
460
500
540
580
600
640
680
720
760
800
840
880

FIGURE C.4.3.4

Table 5.1

Equipment Calibration Dates

Test Cell 7 (DDC 6R-544 Engine)

Engine Speed	Engine Torque	Fuel Flow Meter
30-May-88	30-May-88	07-Jun-88
09-Aug-88	09-Aug-88	24-Aug-88
13-Oct-88	13-Oct-88	13-Oct-88

Test Cell 8 (Cummins NTCC 400 Engine)

Engine Speed	Engine Torque	Fuel Flow Meter
02-Mar-88	02-Mar-88	02-Mar-88
09-Aug-88	04-May-88	
30-Sep-88	09-Aug-88	
	29-Sep-88	
	01-Nov-88	

Dilution Tunnel Calibration

29-Mar-88
23-Jun-88
28-Jul-88

Propane Verification

17-Aug-88
29-Aug-88
16-Sep-88
13-Oct-88
01-Nov-88

Particulate Bench Calibration
02-Sep-88

Emission Bench Calibration

Beckman THC	Beckman CO2	Horiba CO2	Beckman CO	Beckman Hot NOX
04-May-88	04-May-88	04-May-88	04-May-88	04-May-88
16-Aug-88	11-Aug-88	26-Aug-88	11-Aug-88	23-Aug-88
	16-Nov-88			

QUALITY ASSURANCE

The quality assurance plan was included in the monthly reports in the following format :

- Test Cell
- Dilution Tunnel
- Emissions Bench
- Particulate Bench
- CVS System Verification
- Other

Each section listed the equipment used, the calibration method employed and all raw data sheets.

Test Cell 7 Calibrations (DDC 6R-544 Engine)

Engine Speed

Engine Speed was verified by measuring the engine rpm over a range of engine speeds using a Shimpo DT-205 Hand Digital Tachometer and comparing it to the rpm measured with the Hewlett-Packard 1000 computer system.

A 60 tooth gear located on the Eaton dynamometer produces a frequency signal proportional to the engine speed. This signal was supplied to a digital/analog converter and the analog voltage signal was recorded on a Macsym 350 computer.

The analog voltage from the D/A converter was measured over a range of engine speeds and a best-fit 1st order linear regression equation with all errors within 1% calculated. This equation enabled the Macsym 350 computer to convert measured analog voltage from the D/A converter to engine rpm during transient testing.

Dynamometer

Engine torque was measured with an Eaton Dynamatic absorbing eddy current dynamometer rated at 500 Brakehorsepower at 1750 to 6000 rpm. A Lebow 2000 lb. rated strain gauge assembly measures engine torque and transmits an analog voltage signal to a Macsym 350 computer.

Calibration of the Lebow strain gauge involves hanging a series of calibrated weights on the end of the dynamometer calibration arm and recording the voltage produced from the strain gauge.

A best fit 1st order linear regression equation with all errors within 1% was calculated using the analog voltage from the Lebow strain gauge and the calculated torque. This equation enabled the Macsym 350 computer to convert measured strain gauge voltage to engine torque during transient testing.

Fuel Flow Meter

The engine fuel consumption was measured by a model 10E Flow-Tron fuel flow meter capable of a maximum flow capacity of 200 pounds per hour.

Calibration of the fuel flow meter was completed by measuring the mass of diesel fuel with a Fairbanks model 90-7601 scales as it passes through the meter over a measured length of time. The analog voltage signal from the Micro-motion fuel meter and the mass of fuel was recorded over an 8 point calibration procedure.

A best fit 1st order linear regression equation with all errors within 1% was calculated using the analog voltage from the Micro-motion fuel flow meter and calculated fuel flowrate. This equation enabled the Macsym 350 computer to convert the fuel meter voltage signal to a mass fuel flowrate during transient testing.

Test Cell 8 Equipment Calibrations (Cummins NTCC400 Engine)

Engine Speed

Engine Speed was verified by measuring the engine rpm over a range of engine speeds using a Shimpo DT-205 Hand Digital Tachometer and comparing it to the rpm measured with the Hewlett-Packard 1000 computer system.

A 60 tooth gear located on the Eaton dynamometer produces a frequency signal proportional to the engine speed. This signal was supplied to a digital/analog converter and the analog voltage signal was recorded on a Macsym 350 computer.

The analog voltage from the D/A converter was measured over a range of engine speeds and a best-fit 1st order linear regression equation with all errors within 1% calculated as presented in Table D.5.4.2.1 and illustrated in Figure D.5.4.2.1. This equation enabled the Macsym 350 computer to convert measured analog voltage from the D/A converter to engine rpm during transient testing.

Dynamometer

Engine torque was measured with an Eaton Dynamatic absorbing eddy current dynamometer rated at 500 Brakehorsepower at 1750 to 6000 rpm. A Lebow 2000 lb. rated strain gauge assembly measures engine torque and transmits an analog voltage signal to a Macsym 350 computer.

Calibration of the Lebow strain gauge involves hanging a series of calibrated weights on the end of the dynamometer calibration arm and recording the voltage produced from the strain gauge.

A best fit 1st order linear regression equation with all errors within 1% was calculated using the analog voltage from the Lebow strain gauge and the calculated torque. This equation enabled the Macsym 350 computer to convert measured strain gauge voltage to engine torque during transient testing.

Fuel Flow Meter

Fuel flow measurement was completed by measuring the mass of diesel fuel with an Ishida MS-5300 LN scales. These scales were calibrated by the Department of Weight and Measures prior to commencement of the test program.

Dilution Tunnel Calibration

DILUTION TUNNEL CALIBRATION

Pitot Tube Method and Procedure

The velocity of a gas flow can be determined by means of a pitot tube and a differential pressure gauge.

Gas velocity measurements are made by directing the short leg of the pitot tube into the gas stream while keeping the long leg perpendicular to the stack wall. A velocity pressure reading in inches of water is indicated on the manometer to which the pitot tube is attached. A reading is made with the pitot tube located at the centre of each of a number of equal areas in the selected cross section of the duct.

There are no definite rules governing the exact number of traverse points that should be included. It is important that a sufficient number be used to give a representative and accurate result. For example the number of sampling points must be increased with an increase in the cross sectional area of the duct when substantial differences in gas velocities expected.

A sample site criteria of 8-diameters downstream and 2-diameters upstream from any flow disturbances is considered an ideal measurement location. A minimum number of points per traverse can then be utilized. The minimum sampling points required per traverse listed in the following table:

Duct Diameter (ft.)	Minimum Number of Sampling Points Required Per Traverse
Less than 1	2
> 1 I.D. <=2	4
> 2 I.D. <=4	6
> 4 I.D. <=8	10
> 8 I.D. <=16	16
Greater than 16	approval necessary

Traverse points are located at the centres of equal annular areas across two perpendicular diameters.

The location of the traverse points can be found by using the following equation:

$$Rh = Ds \sqrt{\frac{2n-1}{4N}}$$

Where:

Rn = Distance of the n'th traverse point from center (inches)
Ds = Stack diameter (inches)
n = n'th traverse point from center of duct
N = number of traverse points across diameter

One static pressure measurement must be recorded at each traverse location. This is performed by measuring the pressure of the static pressure segment of the pitot tube. Duct temperature and atmospheric barometric pressure should be recorded for each traverse location.

GAS VELOCITY AND FLOWRATE

(Gas Velocity Calculation)

$$Vs = Kp\ Vc \sqrt{\frac{\Delta P\ Ts}{Ms\ Ps}}$$

(Gas Flowrate Calculation)

$$Qs = 60\ Vs\ As \left[\frac{T(ref)\ Ps}{Ts\ P(ref)}\right]$$

WHERE :

Vs = Gas velocity (ft/sec)

Kp = 85.45 ft./sec. $\left[\frac{(lb\ in.Hg)}{lb\ mole\ R\ mm\ H2O}\right]^{1/2}$

Vc = Pitot Tube Coefficient (.99 +- .01)

<>P = Gas Velocity Pressure (in H2O)

Ts = Duct Temperature in Rankine Degrees (F + 460 R)

Ms = 28.90 Stack Gas molecular wt. on actual wet basis (lb/lb)

Pbar = Atmospheric Barometric Pressure (in Hg)

Pstatic = Static Gas Pressure (in H2O)

Ps = Pbar + (Pstatic /13.6)

Qs = Gas flowrate (SCFM)

As = Area of Tunnel (square ft)

T (ref) = Reference Temperature Rankine Degrees (68F + 460 R)

P (ref) = 29.92 (in Hg)

Dilution Tunnel Velocity Pressure Measurements

The dilution tunnel flowrate is currently measured (indirectly) with a standard pitot tube. A micro-manometer; a precision hand-held digital pressure measuring device is used for measuring velocity and static pressures. The specifications of the micro-manometer is presented in Table 1.

The dilution tunnel velocity pressures, static pressures and gas temperatures are measured 100 cm. downstream of the mixing orifice in the 25.4 cm. dilution tunnel. Velocity pressures are collected along two traverses, 90 degrees apart across the diameter of the dilution tunnel. Each traverse consists of 12 points as specified in the following table.

Barometric pressure, as well as wet and dry bulb temperatures are collected during velocity pressure measurement.

Sample Points

Point	Dilution Tunnel	
	T #1 (inches)	T #2
1/	2.84	2.84
2/	2.21	2.21
3/	3.20	3.20
4/	3.23	3.23
5/	3.81	3.81
6/	4.56	4.56
7/	5.64	5.64
8/	8.61	8.61
9/	9.69	9.69
10/	10.44	10.44
11/	11.00	11.00
12/	12.00	12.00

* Distance includes sample port length

Dilution Tunnel Flowrate Calculations

The dilution tunnel gas flowrate at 20 C, 29.92 in Hg (EPA Standard Conditions) is calculate using the gas velocity and flowrate equations. In the velocity calculation the square root of each velocity pressure data point is calculated and the average of the squared values is applied to the flowrate calculation.

A PDP pump calibration factor is then calculated using the following equations :

$$Qpump = \frac{Qs \times 29.92}{PDPpres} \times \frac{PDPtemp}{528}$$

$$Qc = \frac{Qpump}{PDPrpm}$$

WHERE:

Qpump = PDP gas flowrate @ 20C ,29,92 in Hg

Qs = Actual gas flowrate at PDP pump (m3/min)

PDPpres = PDP (inlet pressure + barometric pressure) (in Hg)

PDPtemp = PDP inlet temperature (Rankine)

Qc = PDP calibration factor (m3/rev)

PDPrpm = PDP speed (rpm)

29.92 = Reference Atmospheric Pressure (in Hg)

528 = Reference Temperature, Rankine (68F + 460R)

Emissions Bench Calibration

The following gaseous emission analyzers are currently being used for engine exhaust emission measurement :

GASEOUS ANALYZERS

Analyzer:	Total Hydrocarbon (THC)
Model:	Ratfisch RS55
Working Principal:	Flame Ionization Detector
Ranges:	0-10 ppm 0-100 ppm 0-1000 ppm 0-10,000 ppm
Repeatability:	(+ -) 1 % of full scale

Analyzer:	Total Hydrocarbon (THC)
Model:	Beckman 402
Working Principal:	Flame Ionization Detector
Ranges:	5 ppm - 1 %
Repeatability:	(+ -) 1 % of full scale

Analyzer:	Carbon Dioxide (CO2)
Model:	Beckman Model 864
Working Principal:	Non-Dispersive infrared
Ranges:	0-2.5 % 0-10 % 0-20 %
Repeatability:	(+ -) 1 % of full scale

Analyzer:	Carbon Dioxide (CO2)
Model:	Horiba AIA-21 (Carbon Dioxide)
Working Principal:	Non-Dispersive infrared
Ranges:	0-5 % 0-15 %
Repeatability:	(+ -) 1 % of full scale

Analyzer:	Carbon Monoxide (CO)
Model:	Beckman Model 867
Working Principal:	Non-Dispersive infrared
Ranges:	0-50 ppm 0-200 ppm 0-500 ppm 0-2500 ppm
Repeatability:	(+ -) 1 % of full scale

Analyzer:	Carbon Monoxide (CO)
Model:	Horiba PFR-2000
Working Principal:	Non-Dispersive infrared
Ranges:	0-2 % 0-2.5 % 0-10 %
Repeatability:	(+ -) 1 % of full scale

Analyzer:	Oxides of Nitrogen (NO/NOX) Hot
Model:	Beckman Model 955
Working Principal:	Chemiluminence
Ranges:	0-10 ppm 0-25 ppm 0-100 ppm 0-250 ppm 0-1000 ppm 0-2500 ppm 0-10,000 ppm
Precision:	(+ -) .5 % of full scale

Analyzer:	Oxides of Nitrogen (NO/NOX) Cold
Model:	Beckman Model 951A
Working Principal:	Chemiluminence
Ranges:	0-10 ppm 0-25 ppm 0-100 ppm 0-250 ppm 0-1000 ppm 0-2500 ppm 0-10,000 ppm
Repeatability:	(+ -) .5 % of full scale

Analyzer:	Oxygen (O2)
Model:	Taylor Servomex OA272
Working Principal:	Para-magnetic
Ranges:	0-5 % 0-25 % 0-100 %
Repeatability:	(+ -) 1 % of full scale

Gaseous Analyzer Calibration Gases

Certified Gases

The calibration gases currently used for calibration of the analyzers use in engine emission testing are purchased from Matheson of Canada. These gases are called "Certified Gases" and are certified to the following Certification Accuracy :

Range	Certification Accuracy
1-9 ppm	(+ -) 5 % of Component
10-999 ppm	(+ -) 2 % of Component
0.1 - 2 %	(+ -) 2 % of Component
2 - 50 %	(+ -) 1 % of Component

Primary Standards

Matheson also produces "Primary Standard "calibration gases that are called EPA Protocols and are analyzed using National Bureau of Standards (N.B.S.) standard gases. These Matheson Primary Standard gases are certified to the following accuracy :

Range	Certification Accuracy
1-999 ppm	(+ -) 200 ppm absolute
0.1 - 50 %	or 1.0 % of component which ever is smaller

National Bureau of Standards

The United States National Bureau of Standards produces calibration gases that are certified to the following accuracy :

Gas Constituent	Certification Accuracy
Total Hydrocarbon	> 1 % of component
Carbon Monoxide	> 1 % of component
Carbon Dioxide	> .06% of component
Oxides of Nitrogen	> 1 % of component

The 1984 E.P.A. Federal Register ,Section 86.1314-84 states:

6 (ii) Calibration gases shall be traceable to within 1 percent (%) of NBS. gas standards or other gas standards which have been approved by the Administrator.

6(iii) Span gases shall be accurate to within 2 percent of true concentrations where true concentrations refers to NBS gas standards which have been approved by the Administrator.

The Matheson Primary Standards are traceable to within 1% of the N.B.S. standard gases as required by the E.P.A. Federal Register.

Gaseous Analyzer Calibration Procedure

The following procedure will be used for the calibration of the gaseous analyzers when using the standard gas divider:

ANALYZER CALIBRATION

Make the appropriate zero air and span gas connections to the SGD Stec Inc. (Model 710) standard gas divider (SGD).

Turn the selection valve to the "0" position.

Open the Primary span gas regulator and set the primary span gas divider inlet pressure to 10 psi.

The flow rotameter should indicate no gas flow from the gas divider outlet.

Open the Zero air gas regulator and set the zero air gas divider inlet pressure to 10 psi.

Zero gas will now flow from the gas divider outlet.

Switch the SGD selection valve from 0 to 10 and note the zero air pressure. The pressure should remain constant from setting to setting.

Return the SGD selection indicator to the "0" position. Only zero gas should be flowing from the SGD outlet.

Adjust the analyser Zero pot to obtain an analyzer zero read-out. Record the zero pot value.

Turn the SGD selection indicator to the "10" position.

Adjust the analyser Span pot to obtain a read-out on the analyzer of the same value as the span gas calibration analysis. Only span gas will be flowing from the SGD outlet at this indicator position. Record the span pot value.

Set the SGD selection indicator to 9 , 8 , 7 , 6 , 5 , 4 , 3 , 2 , 1 and 0 and record the analyzer voltage and calculated concentration for each point.

Process the data through the Lotus Regression Program. If the deviation from a least-squares best-fit straight line is 2 percent or less of the value at each data point, concentration values may be calculated by using a single calibration factor for that range. If the deviation exceeds 2 percent at any point, the best fit non-linear equation which represents the data to within 2% of each test point shall be used to determine the concentration.

Gas Renaming

When the analyzer calibration curve has been calculated and installed into the computer system complete the following:

Return the SGD selection indicator to the "0" position. Only zero gas should be flowing from the SGD outlet.

Adjust the analyser Zero pot to obtain an analyzer zero read-out. Record the zero pot value.

Turn the SGD selection indicator to the "10" position

Adjust the analyser Span pot to obtain a read-out on the analyzer of the same value as the span gas calibration analysis. Only span gas will be flowing from the SGD outlet at this indicator position. Record the span pot value.

Introduce the Certified calibration gas through the normal calibration solenoids and note the analyzer value. Mark this value on the bottle; this will be the new calibration value for the calibration gas and will be used when calibrating the instrument.

Repeat the complete procedure for each range of the instrument that will be employed during emission testing.

This procedure will be undertaken each month for every analyzer.

Calculation of Gas Divider correction factor

The dividing accuracy of the gas divider (+ - 0.5% FS) is satisfied when the viscosity of the gas mixture approaches the equivalent of nitrogen gas. When the component gas + the balance gas viscosity is not equivalent to nitrogen gas, divider accuracy deviates greatly.

Gas Divider Correction Factor

Carbon Monoxide (CO) - No correction factor necessary

Carbon Dioxide (CO2) - Correction if concentration greater than 1 %.

Propane (C3 H8) - Correction if concentration greater than 10,000 ppm

Oxides of Nitrogen (NO) - Correction if concentration greater than 10,000 ppm

If a correction factor is needed use the following correction calculation:

Concentration x Divide Number/10 x Correction Factor
Component Gas

Example: In case of 15% CO2/Divide-7

15% x .7 x .9938 = 10.43 %

Particulate Bench Calibration

The particulate bench dry gas meter was calibrated with a bell prover (Gasometer, spirometer). The bell prover which is considered a " Primary Standard " consists of an inverted "bell" which is immersed in water, contained in a somewhat larger vessel. The volume of the cavity under the bell is determined from the cross sectional area of the bell and its height above the liquid level. This information given in terms of volume per unit length displaced is provided by the manufacturer. Thus by noting the displacement by means of a scale, the volume of air introduced into or removed from the bell cavity can be determined. A dry gas meter correction factor is calculated from the ratio of the bell prover volume and the dry gas meter volume over a series of tests at different gas flowrates. The dry gas meter is corrected by multiplying the dry gas meter volume by the correction factor. If the correction factor is greater than 2 % the dry gas meter replaced.

CVS System Verification

DILUTION TUNNEL PROPANE CALIBRATION AND VERIFICATION

EPA 86.1319-84 SAE J0194a 4.1.5 (25.114)

Introduction

The system verification technique involves the injection of a measured amount of propane into the dilution tunnel and a real time total hydrocarbon analyzer measuring the diluted hydrocarbon levels at the gaseous sampling location. If the difference between the injected mass and the calculated mass using the hydrocarbon analyzer ppm values is less than + - 2% then the tunnel is verified to be leak free.

Procedure

Weight the propane lecture bottle using an analytical balance with a resolution of 0.01 grams.

Calibrate the total hydrocarbon analyser for the appropriate range (0-200 ppm).

Connect the pre-weight propane lecture bottle to the critical orifice injection probe which is installed in the dilution tunnels' exhaust gas inlet.

Turn on the Positive Displacement Pump (PDP) and allowing the dilution tunnel temperature and pressure to stabilize.

Load and run the Macsym computers' propane verification data acquisition program.

After 60 seconds from start of recording data; begin injection of the propane tracer gas by fully opening the propane lecture bottle valve (the tunnel concentration should be approximately 120 ppm).

After 300 seconds from start of recording data turn the propane lecture bottle valve closed.

After the Macsym computer has complete taking data (450 seconds) disconnect the propane lecture bottle and put in a secure area.

During testing the Macsym computer will record the following data
PDP Temperature
PDP Pressure
Total Hydrocarbon PPM

Record the following data in the lab book:
Barometric Pressure
Dry Bulb Temperature
Wet Bulb Temperature
PDP rpm

Transfer the collected data to the IBM computer.

Re-weight the propane lecture bottle using an analytical balance with a resolution of 0.01 grams.

Input all values into the Lotus propane verification calculation program and import the collected data into the appropriate area of the spreadsheet.

Print the final calculations. The difference between injected mass and calculate mass should be within 2.0 %.

CALCULATIONS

Equation 1.0

(Mass of Propane from bottle)

Mmass = initial bottle weight - final bottle weight

Mass of Propane in tunnel

The calculations are completed in a Lotus spread sheet. For each second of data the mass of propane is calculated using the calculation shown below. The ambient hydrocarbon ppm is an average of the first and last 20 seconds of collected hydrocarbon ppm values of the collected data.

The sum of the mass of propane for each of the 450 seconds of data is the total calculated mass of propane in the tunnel.

Equation 2.0

(Mass of Propane in Tunnel for each second)

$$Vmix = \frac{Vo * N \times 293 * (Pbar + Ppdp) * 51.91 * ((PPMtun - PPMamb)/3)}{101.325 * Tpdp * .02831685 * 1{,}000{,}000}$$

Equation 3.0

(Total Propane Mass)

$$Mmeas = \text{Sum of } [Vmix * 450 \text{ seconds}]$$

Equation 4.0

(% Difference)

$$\% \text{ Difference} = \frac{Mmeas}{Mmass} * 100 - 100$$

If the mass of propane at the PDP inlet and at the gaseous sample port is different by less than + - 2%, the tunnel is verified to be leak free.

WHERE :

Vmix	= Mass of propane in tunnel (grams)
Vo	= PDP calibration factor (Qc) at ambient conditions (m3/min)
N	= PDP (rpm per sec)
Pbar	= Barometric Pressure (kPa)
Ppdp	= PDP inlet pressure (kPa)
Tpdp	= PDP inlet temperature (K)
PPMtun	= Total Hydrocarbon in dilution tunnel (ppm)
PPMamb	= Total Hydrocarbon in ambient air (ppm)
3	= Propane to Methane conversion
51.91	= Density of propane @ 20C, 101.03 kPa (g/ft3)
101.325	= Standard Pressure @ 20 C
0.02831685	= Conversion factor between L3 and ft3
1,000,000	= Conversion of ppm to grams

% Difference = Difference between calculated mass and propane bottle mass difference

Mmeas = Calculated mass using total hydrocarbon ppm (grams)

Mmass = Propane lecture bottle mass difference.

APPENDIX E: Modified EPA Transient Cycle Emission Data

- NTCC 400
- DDC Series 60

Modified EPA Transient Cycle Mass Emissions - Cummins BTCC400 Engine
10-Nov-88 Official Tests - Fuel "A"
(gr/hp-hr)

Emission	Cold Cycle 1	Hot Cycles 2	3	4	5	6	(HOT CYCLES ONLY) AVG	S.D.	COV	Conf Lim U 95	L 95
BSNOX	4.04	4.21	4.25	4.26	4.26	4.32	4.26	0.04	1	4.30	4.22
BSCO	2.62	2.80	2.72	2.60	2.58	2.51	2.64	0.10	4	2.77	2.51
BSTHC	0.48	0.48	0.49	0.47	0.47	0.47	0.48	0.01	2	0.49	0.47
BSCO2	666	645	662	666	661	646	656	9	1	667	645
TOTAL -UNCOR	0.567	0.499	0.479	0.471	0.468	0.459	0.475	0.01	3	0.492	0.458
BSPART-CORR	0.59	0.514	0.499	0.499	0.503	0.496	0.502	0.01	1	0.510	0.494
SOF -UNCOR	0.063	0.055	0.054	0.059	0.054	0.070	0.058	0.01	10	0.066	0.051
-CORR	0.066	0.056	0.057	0.062	0.058	0.076	0.062	0.01	12	0.071	0.053
SOF%	11.1	11.0	11.3	12.5	11.5	15.3	12.3	1.6	13	14.2	10.4
H -grains h20/lb dry air	56.0	60.6	54.2	47.3	40.5	37.6	48.0	8.5	18	58.6	37.5
Performance											
Avg rpm	1254	1253	1255	1257	1257	1257	1256	2	0	1258	1254
Avg Torq	240	243	242	243	243	243	243	0	0	243	242
Tot Fuel	12.5	11.3	12.0	11.9	11.9	11.6	11.7	0.3	2	12.1	11.4
Work	27.0	27.1	27.0	27.1	27.2	27.2	27.1	0.1	0	27.3	27.0
BSFC	0.464	0.417	0.445	0.439	0.437	0.426	0.433	0.01	2	0.445	0.420

Cummins BTCC400 Modified EPA Transient Cycle Data (Weighted Emissions)

BSNOX	4.22 gr/hp-hr
BSCO	2.66 gr/hp-hr
BSTHC	0.48 gr/hp-hr
BSCO2	656 gr/hp-hr
TOTAL -UNCOR	0.492 gr/hp-hr
BSPART-CORR	0.516 gr/hp-hr
SOF -UNCOR	0.059 gr/hp-hr
-CORR	0.062 gr/hp-hr
SOF%	12.0 %

Modified EPA Transient Cycle Mass Emissions - Cummins NTCC400 Engine
17-Nov-88 Official Tests - Fuel "B"
(gr/hp-hr)

Emission	Cold Cycle 1	Hot Cycles 2	3	4	5	6	7	(HOT CYCLES ONLY) AVG	S.D.	COV	Conf Lim U 95	L 95
BSNOX	4.80	4.78	4.52	4.48	4.58	4.55	4.57	4.58	0.10	2	4.69	4.47
BSCO	2.61	2.25	2.23	2.25	2.22	2.18	2.18	2.22	0.03	1	2.25	2.18
BSTHC	0.52	0.41	0.40	0.40	0.41	0.41	0.41	0.41	0.00	1	0.41	0.40
BSCO2	709	689	670	675	676	672	675	676	6	1	683	669
TOTAL -UNCOR	0.599	0.489	0.503	0.507	0.506	0.497	0.498	0.500	0.01	1	0.507	0.493
BSPART-CORR	0.663	0.512	0.558	0.565	0.562	0.553	0.555	0.551	0.02	3	0.571	0.530
SOF -UNCOR	0.112	0.074	0.092	0.082	0.082	0.090	0.084	0.084	0.01	7	0.091	0.077
-CORR	0.124	0.077	0.103	0.091	0.091	0.100	0.094	0.093	0.01	9	0.102	0.083
SOF%	18.7	15.1	18.3	16.2	16.2	18.1	16.9	16.8	1.1	7	18.1	15.5
H -grains h20/lb dry air	26.5	52.8	25.4	23.5	25.4	23.9	23.9	29.2	10.6	36	41.4	17.0
Performance												
Avg rpm	1255	1257	1257	1257	1256	1257	1256	1257	0	0	1257	1256
Avg Torq	238	241	242	242	240	243	241	241	1	0	242	240
Tot Fuel	12.6	12.1	11.9	12.2	11.9	11.9	12.1	12.0	0.1	1	12	12
Work	27.0	27.1	27.2	27.1	27.0	27.2	27.1	27.1	0.1	0	27	27
BSFC	0.467	0.446	0.438	0.450	0.441	0.438	0.446	0.443	0.00	1	0.448	0.437

Cummins NTCC400 Modified EPA Transient Cycle Data (Weighted Emissions)

BSNOX	4.50	gr/hp-hr
BSCO	2.27	gr/hp-hr
BSTHC	0.42	gr/hp-hr
BSCO2	681	gr/hp-hr
TOTAL -UNCOR	0.514	gr/hp-hr
BSPART-CORR	0.567	gr/hp-hr
SOF -UNCOR	0.088	gr/hp-hr
-CORR	0.097	gr/hp-hr
SOF%	17.1	%

Modified EPA Transient Cycle Mass Emissions - Cummins BTCC400 Engine
04-Nov-88 Official Tests - Fuel "C"
(gr/hp-hr)

Emission	Cold Cycle 1	Hot Cycles 2	3	4	5	6	7	(HOT CYCLES ONLY) AVG	S.D.	C0V	Conf Lim U 95	L 95
BSNOX	3.93	4.09	4.21	4.29	4.10	4.11	4.14	4.16	0.07	2	4.24	4.07
BSCO	2.70	2.70	2.70	2.77	2.79	2.75	2.79	2.75	0.04	1	2.79	2.71
BSTHC	0.49	0.40	0.39	0.36	0.42	0.41	0.41	0.40	0.02	5	0.42	0.38
BSCO2	684	644	648	636	649	657	620	642	12	2	656	629
TOTAL -UBCOR	0.533	0.461	0.482	0.460	0.464	0.464	0.460	0.468	0.01	1	0.476	0.460
BSPART-CORR	0.565	0.488	0.500	0.481	0.476	0.484	0.484	0.486	0.01	2	0.494	0.477
SOF -UBCOR	0.097	0.081	0.072	0.074	0.062	0.065	0.072	0.071	0.01	9	0.078	0.064
-CORR	0.103	0.085	0.074	0.076	0.063	0.068	0.075	0.074	0.01	9	0.081	0.066
SOF%	18.2	17.6	14.9	15.8	13.4	14.8	15.4	15.2	1.3	9	16.7	13.6
H -grains h20/lb dry air	46.8	48.3	56.7	61.5	62.7	54.4	58.5	57.0	4.8	8	62.5	51.5
Performance												
Avg rpm	1259	1260	1261	1261	1261	1261	1262	1261	1	0	1262	1261
Avg Torq	248	253	253	253	251	253	253	252	1	0	253	252
Tot Fuel	12.6	12.1	12.3	12.2	12.5	12.4	12.1	12.3	0.1	1	12.5	12.1
Work	27.8	28.2	28.1	28.1	28.1	28.2	28.1	28.1	0.0	0	28.2	28.1
BSFC	0.454	0.429	0.437	0.434	0.445	0.440	0.431	0.438	0.01	1	0.444	0.431

Cummins BTCC400 Modified EPA Transient Cycle Data (Weighted Emissions)

BSNOX	4.12	g/hr
BSCO	2.75	g/hr
BSTHC	0.41	g/hr
BSCO2	648	g/hr
TOTAL -UBCOR	0.477	g/hr
BSPART-CORR	0.497	g/hr
SOF -UBCOR	0.075	g/hr
-CORR	0.078	g/hr
SOF%	15.6	%

Modified EPA Transient Cycle Mass Emissions - Cummins NTCC400 Engine
24-Nov-88 Official Tests - Fuel "D"
(gr/hp-hr)

Emission	Cold Cycle 1	Hot Cycles 2	3	4	5	6	7	(HOT CYCLES ONLY) AVG	S.D.	COV	Conf Lim U 95	L 95
BSNOX	4.28	4.66	4.60	4.65	4.67	4.63	4.57	4.63	0.04	1	4.67	4.59
BSCO	2.04	2.42	2.33	2.24	2.25	2.29	2.31	2.31	0.06	3	2.38	2.24
BSTHC	0.58	0.44	0.43	0.46	0.44	0.44	0.44	0.44	0.01	2	0.45	0.43
BSCO2	741	695	697	683	695	685	689	690	5	1	696	684
TOTAL -UNCOR	0.653	0.535	0.532	0.545	0.528	0.548	0.535	0.537	0.01	1	0.545	0.529
BSPART-CORR	0.726	0.589	0.588	0.603	0.581	0.603	0.590	0.592	0.01	1	0.602	0.583
SOF -UNCOR	0.137	0.095	0.088	0.107	0.099	0.095	0.094	0.096	0.01	6	0.103	0.090
-CORR	0.153	0.104	0.097	0.119	0.109	0.104	0.103	0.106	0.01	6	0.114	0.098
SOF%	21.0	17.8	16.5	19.6	18.8	17.3	17.6	17.9	1.0	6	19.1	16.8
H -grains h20/lb dry air	24.5	28.8	27.3	27.3	29.4	29.4	28.6	28.4	0.9	3	29.4	27.4
Performance												
Avg rpm	1258	1256	1258	1260	1258	1258	1258	1258	1	0	1260	1257
Avg Torq	240	245	245	245	246	246	245	245	0	0	246	245
Tot Fuel	*12.6	12.3	12.2	12.3	12.4	12.1	12.4	12.3	0.1	1	12.4	12.2
Work	27.1	27.5	27.4	27.5	27.5	27.5	27.5	27.5	0.0	0	27.5	27.4
BSFC	0.465	0.447	0.445	0.448	0.451	0.440	0.451	0.447	0.00	1	0.451	0.443

Cummins NTCC400 Modified EPA Transient Cycle Data (Weighted Emissions)

BSNOX	4.58 gr/hp-hr
BSCO	2.38 gr/hp-hr
BSTHC	0.46 gr/hp-hr
BSCO2	698 gr/hp-hr
TOTAL -UNCOR	0.554 gr/hp-hr
BSPART-CORR	0.611 gr/hp-hr
SOF -UNCOR	0.102 gr/hp-hr
-CORR	0.113 gr/hp-hr
SOF%	18.4 %

Modified EPA Transient Cycle Mass Emissions - Cummins NTCC400 Engine
08-Dec-88 Official Tests - Fuel "E"
(gr/hp-hr)

Emission	Cold Cycle 1	Hot Cycles 2	3	4	5	6	7	(HOT CYCLES ONLY) AVG	S.D.	COV	Conf Lim U 95	L 95
BSNOX	4.14	4.55	4.44	4.39	4.42	4.37	4.41	4.43	0.06	1	4.50	4.36
BSCO	2.56	2.15	2.15	2.11	2.05	2.07	2.03	2.09	0.05	2	2.15	2.04
BSTHC	0.53	0.39	0.39	0.41	0.41	0.40	0.40	0.40	0.01	2	0.41	0.39
BSCO2	723	701	681	690	693	697	694	693	6	1	700	685
TOTAL -UNCOR	0.655	0.514	0.536	0.517	0.505	0.516	0.511	0.517	0.01	2	0.528	0.505
BSPART-CORR	0.734	0.568	0.597	0.580	0.567	0.579	0.574	0.578	0.01	2	0.589	0.566
SOF -UNCOR	0.155	0.116	0.118	0.118	0.124	0.125	0.126	0.121	0.00	3	0.126	0.117
-CORR	0.173	0.128	0.131	0.132	0.139	0.140	0.142	0.135	0.01	4	0.141	0.129
SOF%	23.7	22.6	22.0	22.8	24.6	24.2	24.7	23.5	1.0	4	24.7	22.3
H -grains h20/lb dry air	20.0	27.7	24.0	20.0	20.5	20.5	20.5	22.4	2.7	12	25.5	19.2
Performance												
Avg rpm	1259	1261	1262	1262	1262	1261	1262	1262	0	0	1262	1261
Avg Torq	243	247	248	249	248	249	247	248	1	0	249	247
Tot Fuel	13.2	12.6	12.3	12.4	12.3	12.6	12.3	12.4	0.1	1	12.5	12.2
Work	27.4	27.7	27.7	27.9	27.8	28.0	27.8	27.8	0.1	0	27.9	27.7
BSFC	0.482	0.454	0.444	0.445	0.442	0.451	0.443	0.445	0.00	1	0.450	0.440

Cummins NTCC400 Modified EPA Transient Cycle Data (Weighted Emissions)

BSNOX	4.39 gr/hp-hr
BSCO	2.16 gr/hp-hr
BSTHC	0.42 gr/hp-hr
BSCO2	697 gr/hp-hr
TOTAL -UNCOR	0.536 gr/hp-hr
BSPART-CORR	0.600 gr/hp-hr
SOF -UNCOR	0.126 gr/hp-hr
-CORR	0.141 gr/hp-hr
SOF%	23.5 %

Modified EPA Transient Cycle Mass Emissions - Cummins NTCC400 Engine
21-Oct-88 Official Tests - Fuel "F"
(gr/hp-hr)

Emission	Cold Cycle 1	Hot Cycles 2	3	4	5	6	(HOT CYCLES ONLY) AVG	S.D.	COV	Conf Lim U 95	L 95
BSNOX	4.31	4.40	4.51	4.56	4.40	4.37	4.45	0.07	2	4.54	4.36
BSCO	2.84	2.55	2.58	2.71	2.50	2.55	2.58	0.07	3	2.67	2.49
BSTHC	0.46	0.52	0.51	0.48	0.50	0.47	0.50	0.02	4	0.52	0.47
BSCO2	657	657.33	640	635	637	638	642	8	1	652	632
TOTAL -UNCOR	0.490	0.419	0.420	0.425	0.412	0.418	0.419	0.00	1	0.424	0.414
BSPART-CORR	0.530	0.452	0.450	0.449	0.440	0.446	0.447	0.00	1	0.453	0.442
SOF -UNCOR	0.052	0.048	0.039	0.053	0.042	0.049	0.046	0.01	11	0.052	0.040
-CORR	0.055	0.052	0.041	0.056	0.045	0.052	0.049	0.01	11	0.056	0.042
SOF%	10.4	11.5	9.3	12.5	10.2	11.7	11.0	1.1	10	12.4	9.6
H -grains h20/lb dry air	45.1	39.2	42.2	48.2	44.0	44.0	43.5	2.9	7	47.2	39.9
Performance											
Avg rpm	1234	1234	1235	1232	1235	1236	1234	1	0	1236	1233
Avg Torq	251	252	252	253	253	253	253	1	0	253	252
Tot Fuel	12.4	11.7	11.7	11.9	11.7	11.9	11.8	0.1	1	11.9	11.7
Work	27.5	27.6	27.5	27.6	27.6	27.7	27.6	0.1	0	27.7	27.5
BSFC	0.452	0.425	0.426	0.431	0.424	0.430	0.427	0.00	1	0.431	0.424

Cummins NTCC400 Modified EPA Transient Cycle Data (Weighted Emissions)

BSNOX	4.42 gr/hp-hr
BSCO	2.61 gr/hp-hr
BSTHC	0.49 gr/hp-hr
BSCO2	646 gr/hp-hr
TOTAL -UNCOR	0.430 gr/hp-hr
BSPART-CORR	0.460 gr/hp-hr
SOF -UNCOR	0.047 gr/hp-hr
-CORR	0.050 gr/hp-hr
SOF%	11.0 %

* Note Cold Cycle is from Oct 20/1988

Modified EPA Transient Cycle Mass Emissions - Cummins NTCC400 Engine
28-Oct-88 Official Tests - Fuel "F"
(gr/hp-hr)

Emission	Cold Cycle 1	Hot Cycles 2	3	4	5	6	7	(HOT CYCLES ONLY) AVG	S.D.	COV	Conf Lim U 95	L 95
BSNOX	4.31	4.59	4.68	4.62	4.66	4.69	4.56	4.63	0.05	1	4.69	4.58
BSCO	2.04	2.53	2.42	2.34	2.37	2.39	2.32	2.40	0.07	3	2.47	2.32
BSTHC	0.46	0.49	0.50	0.47	0.47	0.47	0.48	0.48	0.01	2	0.49	0.47
BSCO2	657	619	634	645	630	632	629	631	8	1	640	623
TOTAL -UNCOR	0.498	0.412	0.374	0.371	0.384	0.384	0.373	0.383	0.01	4	0.399	0.367
BSPART-CORR	0.530	0.448	0.417	0.412	0.428	0.426	0.420	0.425	0.01	3	0.438	0.412
SOF -UNCOR	0.052	0.041	0.042	0.050	0.045	0.045	0.043	0.044	0.00	7	0.048	0.041
-CORR	0.055	0.045	0.046	0.056	0.050	0.050	0.049	0.049	0.00	7	0.053	0.045
SOF%	10.4	10.0	11.2	13.5	11.7	11.7	11.5	11.6	1.0	9	12.8	10.4
H -grains h20/lb dry air	45.1	35.6	24.1	25.4	24.0	25.4	19.3	25.6	4.9	19	31.3	20.0

Performance

Avg rpm	1234	1235	1234	1235	1236	1234	1234	1235	1	0	1235	1234
Avg Torq	251	253	252	253	252	253	253	253	1	0	253	252
Tot Fuel	12.4	11.3	11.4	12.2	11.7	11.7	11.6	11.7	0.3	2	12.1	11.4
Work	27.5	27.6	27.5	27.7	27.5	27.5	27.2	27.5	0.1	1	27.6	27.3
BSFC	0.452	0.410	0.415	0.441	0.426	0.425	0.426	0.427	0.01	2	0.438	0.415

Cummins NTCC400 Modified EPA Transient Cycle Data (Weighted Emissions)

BSNOX	4.59 gr/hp-hr
BSCO	2.46 gr/hp-hr
BSTHC	0.48 gr/hp-hr
BSCO2	635 gr/hp-hr
TOTAL -UNCOR	0.399 gr/hp-hr
BSPART-CORR	0.440 gr/hp-hr
SOF -UNCOR	0.045 gr/hp-hr
-CORR	0.050 gr/hp-hr
SOF%	11.4 %

Modified EPA Transient Cycle Mass Emissions - Cummins NTCC400 Engine
01-Dec-88 Official Tests - Fuel "F"
(gr/hp-hr)

Emission	Cold Cycle 1	Hot Cycles 2	3	4	5	6	7	(HOT CYCLES ONLY) AVG	S.D.	COV	Conf Lim U 95	L 95
BSNOX	4.14	4.31	4.30	4.44	4.48	4.52	4.56	4.45	0.08	2	4.55	4.35
BSCO	2.85	2.57	2.56	2.52	2.45	2.50	2.43	2.51	0.05	2	2.56	2.45
BSTHC	0.55	0.50	0.50	0.48	0.49	0.49	0.49	0.49	0.01	1	0.50	0.48
BSCO2	705	690	685	657	669	674	670	676	11	2	688	663
TOTAL -UNCOR	0.512	0.433	0.426	0.411	0.418	0.412	0.416	0.419	0.01	2	0.428	0.410
BSPART-CORR	0.565	0.480	0.473	0.456	0.464	0.458	0.459	0.465	0.01	2	0.475	0.455
SOF -UNCOR	0.052	0.042	0.043	0.047	0.046	0.042	0.045	0.044	0.00	4	0.046	0.042
-CORR	0.058	0.046	0.047	0.053	0.051	0.046	0.050	0.049	0.00	5	0.052	0.046
SOF%	10.2	9.7	10.1	11.4	11.0	10.2	10.8	10.5	0.6	6	11.2	9.9
H -grains h20/lb dry air	28.2	25.2	25.2	25.2	25.2	25.7	28.6	25.9	1.2	5	27.3	24.4
Performance												
Avg rpm	1231	1232	1232	1232	1233	1233	1233	1233	1	0	1233	1232
Avg Torq	247	250	249	253	249	249	249	250	1	0	251	249
Tot Fuel	12.5	11.9	11.9	11.7	11.7	11.7	11.7	11.7	0.1	1	11.8	11.6
Work	27.0	27.4	27.3	27.6	27.2	27.2	27.2	27.3	0.2	1	27.5	27.1
BSFC	0.462	0.434	0.437	0.424	0.430	0.430	0.430	0.430	0.00	1	0.435	0.426

Cummins NTCC400 Modified EPA Transient Cycle Data (Weighted Emissions)

BSNOX	4.40	g/hr
BSCO	2.55	g/hr
BSTHC	0.50	g/hr
BSCO2	680	g/hr
TOTAL -UNCOR	0.433	g/hr
BSPART-CORR	0.479	g/hr
SOF -UNCOR	0.045	g/hr
-CORR	0.050	g/hr
SOF%	10.5	%

Modified EPA Transient Cycle Mass Emissions - DDC Series 60 Engine
Official Tests - Fuel "A" (OCT 15/88)
(gr/hp-hr)

Emission	Cold Cycle 1	Hot Cycles 2	3	4	5	6	(HOT CYCLES ONLY) AVG	S.D.	COV	Conf Lim U 95	L 95
BSNOX	4.74	4.50	4.51	4.48	4.46	4.49	4.49	0.02	0	4.51	4.47
BSCO	3.55	2.21	2.21	2.21	2.22	2.26	2.22	0.02	1	2.25	2.20
BSTHC	0.67	0.31	0.30	0.29	0.30	0.30	0.30	0.01	2	0.31	0.29
BSCO2	641	603	604	602	607	604	604	2	0	606	602
TOTAL -UNCOR	0.206	0.200	0.194	0.201	0.193	0.198	0.197	0.00	2	0.201	0.193
BSPART-CORR	0.306	0.214	0.207	0.215	0.205	0.210	0.210	0.00	2	0.215	0.205
SOF -UNCOR	0.159	0.075	0.069	0.067	0.067	0.076	0.071	0.00	6	0.076	0.066
-CORR	0.170	0.088	0.074	0.072	0.072	0.081	0.076	0.00	5	0.081	0.071
SOF%	55.6%	37.5%	35.6%	33.3%	34.7%	38.4%	35.9%	1.8%	5	38.2%	33.6%
H -grains h20/lb dry air	42.7	44.3	42.2	43.5	45.0	46.7	44.5	1.6	4	46.5	42.5
Performance											
Avg rpm	1002	998	1001	1000	1001	1001	1000	1	0	1002	999
Avg Torq	238	239	239	238	237	237	238	1	0	239	237
Tot Fuel	8.9	8.4	8.4	8.4	8.4	8.4	8.4	0.0	0	8	8
Work	21.7	21.9	21.9	21.9	21.8	21.7	21.8	0.1	0	22	22
BSFC	0.411	0.385	0.384	0.385	0.386	0.388	0.385	0.00	0	0.386	0.383

DDC Series 60 Modified EPA Transient Cycle Data (Weighted Emissions)

BSNOX	4.53
BSCO	2.41
BSTHC	0.35
BSCO2	609
TOTAL -UNCOR	0.210
BSPART-CORR	0.224
SOF -UNCOR	0.084
-CORR	0.090
SOF%	38.9%

Modified EPA Transient Cycle Mass Emissions - DDC Series 60 Engine
Official Tests - Fuel "B" (NOV 8/88)
(gr/hp-hr)

Emission	Cold Cycle 1	Hot Cycles 2	3	4	5	6	7	(HOT CYCLES ONLY) AVG	S.D.	COV	Conf Lim U 95	L 95
BSNOX	4.78	4.69	4.62	4.63	4.59	4.57	4.59	4.62	0.04	1	4.66	4.57
BSCO	3.90	2.23	2.70	2.46	2.47	2.60	2.53	2.50	0.15	6	2.66	2.33
BSTHC	0.95	0.35	0.31	0.31	0.31	0.30	0.30	0.31	0.02	5	0.33	0.29
BSCO2	639	619	600	596	591	611	589	601	11	2	613	589
TOTAL -UNCOR	0.619	0.223	0.228	0.217	0.227	0.241	0.228	0.227	0.01	3	0.236	0.219
BSPART-CORR	0.659	0.237	0.244	0.231	0.243	0.258	0.243	0.243	0.01	3	0.252	0.233
SOF -UNCOR	0.494	0.097	0.074	0.093	0.087	0.108	0.093	0.092	0.01	11	0.104	0.080
-CORR	0.526	0.104	0.079	0.099	0.093	0.115	0.099	0.098	0.01	11	0.111	0.086
SOF%	79.0%	43.5%	32.5%	42.9%	38.3%	44.8%	40.8%	40.5%	0.0	10	0.5	0.4
H -grains h20/lb dry air	44.7	44.8	42.5	44.8	41.8	42.7	43.8	43.4	1.2	3	44.7	42.1
Performance												
Avg rpm	1006	1006	1006	1004	1006	1001	1006	1005	2	0	1007	1003
Avg Torq	247	248	247	247	247	248	250	248	1	0	249	247
Tot Fuel	9.3	8.7	8.7	8.8	8.7	8.7	8.7	8.7	0.0	0	9	9
Work	22.7	22.7	22.7	22.7	22.6	22.8	23.1	22.8	0.1	1	23	23
BSFC	0.408	0.383	0.385	0.386	0.385	0.383	0.378	0.383	0.00	1	0.386	0.380

DDC Series 60 Modified EPA Transient Cycle Data (Weighted Emissions)

BSNOX	4.65
BSCO	2.66
BSTHC	0.41
BSCO2	611
TOTAL -UNCOR	0.283
BSPART-CORR	0.301
SOF -UNCOR	0.150
-CORR	0.160
SOF%	46.5%

Modified EPA Transient Cycle Mass Emissions - DDC Series 60 Engine
Official Tests - Fuel "C" (NOV 15/88)
(gr/hp-hr)

Emission	Cold Cycle 1	Hot Cycles 2	3	4	5	6	7	(HOT CYCLES ONLY) AVG	S.D.	COV	Conf Lim U 95	L 95
BSNOX	4.62	4.34	4.20	4.29	4.31	4.31	4.29	4.29	0.04	1	4.34	4.24
BSCO	2.07	2.07	1.90	1.97	1.94	1.90	2.02	1.98	0.05	3	2.04	1.92
BSTHC	0.10	0.13	0.15	0.15	0.15	0.14	0.16	0.15	0.01	6	0.16	0.14
BSCO2	633	597	585	585	590	589	591	590	4	1	594	585
TOTAL -UNCOR	0.200	0.169	0.168	0.170	0.173	0.171	0.174	0.171	0.00	1	0.173	0.168
BSPART-CORR	0.220	0.183	0.185	0.185	0.189	0.186	0.189	0.186	0.00	1	0.189	0.184
SOF -UNCOR	0.054	0.047	0.047	0.048	0.048	0.047	0.044	0.047	0.00	3	0.048	0.045
-CORR	0.060	0.051	0.052	0.052	0.053	0.051	0.047	0.051	0.00	4	0.053	0.049
SOF%	27.0%	27.8%	28.0%	28.2%	27.7%	27.5%	25.3%	27.4%	0.0	4	0.3	0.3
H -grains h20/lb dry air	29.1	34.9	29.3	33.6	32.2	35.6	36.1	33.6	2.3	7	36.2	31.0
Performance												
Avg rpm	1010	1004	1006	1004	1004	1004	1005	1005	1	0	1005	1004
Avg Torq	246	246	246	248	246	247	246	247	1	0	247	246
Tot Fuel	9.1	8.5	8.5	8.6	8.6	8.6	8.5	8.6	0.1	1	9	8
Work	22.6	22.7	22.7	22.8	22.7	22.7	22.7	22.7	0.0	0	23	23
BSFC	0.401	0.375	0.375	0.376	0.377	0.379	0.376	0.376	0.00	0	0.378	0.375

DDC Series 60 Modified EPA Transient Cycle Data (Weighted Emissions)

BSNOX	4.34
BSCO	2.11
BSTHC	0.15
BSCO2	597
TOTAL -UNCOR	0.174
BSPART-CORR	0.190
SOF -UNCOR	0.048
-CORR	0.053
SOF%	27.7%

Modified EPA Transient Cycle Mass Emissions - DDC Series 60 Engine
Official Tests - Fuel "D" (NOV 22/88)
(gr/hp-hr)

Emission	Cold Cycle 1	Hot Cycles 2	3	4	5	6	7	(HOT CYCLES ONLY) AVG	S.D.	COV	Conf Lim U 95	L 95
BSNOX	4.97	4.74	4.75	4.70	4.72	4.75	4.77	4.74	0.02	0	4.76	4.71
BSCO	3.84	2.25	2.18	2.21	2.20	2.23	2.22	2.22	0.02	1	2.24	2.19
BSTHC	0.86	0.33	0.29	0.30	0.29	0.31	0.32	0.31	0.01	5	0.32	0.29
BSCO2	630	605	601	606	595	596	600	600	4	1	605	596
TOTAL -UNCOR	0.453	0.272	0.269	0.269	0.266	0.272	0.290	0.273	0.01	3	0.282	0.264
BSPART-CORR	0.496	0.300	0.297	0.298	0.294	0.299	0.319	0.301	0.01	3	0.310	0.292
SOF -UNCOR	0.300	0.117	0.115	0.112	0.112	0.112	0.120	0.115	0.00	3	0.118	0.111
-CORR	0.329	0.129	0.127	0.124	0.124	0.124	0.132	0.127	0.00	2	0.130	0.123
SOF%	66.2%	43.0%	42.8%	41.6%	42.1%	41.2%	41.4%	42.0%	0.8	2	0.4	0.4
H -grains h20/lb dry air	31.2	27.7	27.3	26.3	26.4	28.4	28.4	27.4	0.8	3	28.4	26.5
Performance												
Avg rpm	1001	1002	1002	1004	1003	1004	1005	1003	1	0	1005	1002
Avg Torq	246	245	247	247	247	246	248	246	1	0	247	246
Tot Fuel	9.3	8.7	8.7	8.7	8.7	8.7	8.7	8.7	0.0	0	9	9
Work	22.5	22.6	22.7	22.7	22.7	22.7	22.8	22.7	0.1	0	23	23
BSFC	0.411	0.387	0.385	0.384	0.384	0.384	0.381	0.384	0.00	0	0.386	0.382

DDC Series 60 Modified EPA Transient Cycle Data (Weighted Emissions)

BSNOX	4.77
BSCO	2.45
BSTHC	0.39
BSCO2	605
TOTAL -UNCOR	0.296
BSPART-CORR	0.326
SOF -UNCOR	0.141
-CORR	0.155
SOF%	45.7%

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Modified EPA Transient Cycle Mass Emissions - DDC Series 60 Engine
Official Tests - Fuel "E" (Dec 6/88)
(gr/hp-hr)

Emission	Cold Cycle 1	Hot Cycles 2	3	4	5	6	(HOT CYCLES ONLY) AVG	S.D.	COV	Conf Lim U 95	L 95
BSNOX	4.78	4.56	4.50	4.54	4.43	4.52	4.51	0.04	1	4.57	4.45
BSCO	3.43	2.20	2.19	2.17	2.17	2.20	2.19	0.01	0	2.01	2.77
BSTHC	0.57	0.26	0.25	0.24	0.28	0.26	0.26	0.01	3	0.43	0.39
BSCO2	625	602	603	596	602	601	601	2	0	604	598
TOTAL -UNCOR	0.516	0.242	0.236	0.237	0.245	0.246	0.241	0.00	2	0.246	0.236
BSPART-CORR	0.562	0.264	0.257	0.260	0.270	0.269	0.264	0.01	2	0.270	0.258
SOF -UNCOR	0.194	0.082	0.081	0.081	0.084	0.069	0.079	0.01	7	0.086	0.073
-CORR	0.211	0.089	0.088	0.089	0.093	0.075	0.087	0.01	7	0.094	0.079
SOF%	37.6%	33.9%	34.3%	34.2%	34.3%	28.0%	32.9%	2.5%	7	36.0%	29.9%
H -grains h20/lb dry air	33.9	32.9	32.9	31.6	29.0	33.1	31.9	1.5	5	33.0	30.0

Performance											
Avg rpm	1007	1000	1001	1001	1004	1001	1001	1	0	1003	1000
Avg Torq	250	247	248	246	248	247	247	1	0	248	247
Tot Fuel	9.2	8.7	8.7	8.6	8.6	8.7	8.7	0.0	1	9	9
Work	22.8	22.7	22.8	22.7	22.8	22.7	22.7	0.0	0	23	23
BSFC	0.405	0.383	0.380	0.381	0.379	0.381	0.381	0.00	0	0.383	0.379

DDC Series 60 Modified EPA Transient Cycle Data (Weighted Emissions)

BSNOX	4.56
BSCO	2.37
BSTHC	0.30
BSCO2	604
TOTAL -UNCOR	0.281
BSPART-CORR	0.307
SOF -UNCOR	0.096
-CORR	0.105
SOF%	33.7%

Modified EPA Transient Cycle Mass Emissions - DDC Series 60 Engine
Official Tests - Fuel "F" (NOV 29/88)
(gr/hp-hr)

Emission	Cold Cycle 1	Hot Cycles 2	3	4	5	6	(HOT CYCLES ONLY) AVG	S.D.	COV	Conf Lim U 95	L 95
BSNOX	4.57	4.48	4.53	4.55	4.49	4.50	4.51	0.03	1	4.54	4.48
BSCO	3.09	2.24	2.30	2.24	2.21	2.17	2.23	0.04	2	2.28	2.18
BSTHC	1.18	0.40	0.42	0.40	0.40	0.39	0.40	0.01	2	0.41	0.39
BSCO2	613	592	590	594	596	587	593	4	1	598	589
TOTAL -UNCOR	0.258	0.179	0.177	0.179	0.178	0.186	0.180	0.00	2	0.184	0.176
BSPART-CORR	0.287	0.199	0.196	0.198	0.197	0.206	0.199	0.00	2	0.204	0.195
SOF -UNCOR	0.146	0.072	0.072	0.076	0.063	0.080	0.073	0.01	8	0.080	0.066
-CORR	0.163	0.08	0.08	0.085	0.07	0.089	0.081	0.01	8	0.089	0.073
SOF%	56.6%	40.2%	40.7%	42.5%	35.4%	43.0%	40.4%	2.7%	7	43.7%	37.0%
H -grains h20/lb dry air	24.1	25.6	25.6	26.0	24.9	25.0	25.6	0.7	3	26.4	24.7
Performance											
Avg rpm	989	986	989	988	991	993	989	2	0	992	986
Avg Torq	233	237	237	237	237	238	237	0	0	237	237
Tot Fuel	8.2	8.1	8.1	8.1	8.1	8.1	8.1	0.0	0	8	8
Work	21.0	21.4	21.3	21.4	21.5	21.5	21.4	0.1	0	22	21
BSFC	0.393	0.379	0.381	0.381	0.378	0.377	0.379	0.00	0	0.381	0.377

DDC Series 60 Modified EPA Transient Cycle Data (Weighted Emissions)

BSNOX	4.51
BSCO	2.36
BSTHC	0.51
BSCO2	596
TOTAL -UNCOR	0.191
BSPART-CORR	0.212
SOF -UNCOR	0.083
-CORR	0.092
SOF%	42.7%

Modified EPA Transient Cycle Mass Emissions - DDC Series 60 Engine
Official Tests - Fuel "F" (SEPT 20/88)
(gr/hp-hr)

Emission	Cold Cycle 1	Hot Cycles 2	3	4	5	6	(HOT CYCLES ONLY) AVG	S.D.	COV	Conf Lim U 95	L 95
BSNOX	4.58	4.45	4.55		4.60	4.69	4.59	0.10	2	4.72	4.47
BSCO	4.29	2.50	2.44		2.47	2.43	2.46	0.03	1	2.49	2.43
BSTHC	1.93	0.49	0.49		0.47	0.45	0.48	0.02	3	0.50	0.45
BSCO2	629	609	583		583	598	593	11	2	607	580
TOTAL -UNCOR	0.365	0.201	0.197		0.215	0.199	0.203	0.01	3	0.212	0.194
BSPART-CORR	0.359	0.198	0.196		0.214	0.198	0.202	0.01	4	0.211	0.192
SOF -UNCOR	0.219	0.066	0.073		0.069	0.075	0.071	0.00	5	0.075	0.066
-CORR	0.216	0.065	0.073		0.069	0.074	0.070	0.00	5	0.075	0.066
SOF%	60.0%	32.8%	37.1%		32.1%	37.7%	34.9%	2.5%	7	38.0%	31.8%
H -grains h20/lb dry air	83.9	82.1	77.2		77.1	77.1	78.4	2.2	3	81.0	75.7
Performance											
Avg rpm	983	983	982		978	978	980	2	0	983	977
Avg Torq	233	232	233		234	234	233	1	0	234	232
Tot Fuel	0.7	0.1	0.1		0.0	0.1	0.1	0.0	1	0	0
Work	21.1	21.0	21.2		21.2	21.2	21.1	0.1	0	21	21
BSFC	0.41	0.38	0.38		0.38	0.38	0.382	0.00	0	0.383	0.381

DDC Series 60 Modified EPA Transient Cycle Data (Weighted Emissions)

BSNOX	3.91
BSCO	2.38
BSTHC	0.62
BSCO2	516
TOTAL -UNCOR	0.197
BSPART-CORR	0.195
SOF -UNCOR	0.001
-CORR	0.000
SOF%	33.2%

APPENDIX F: Project Management Summary

Project Management

December, 1987

A meeting was held between ORTECH, the Petroleum Committee, Mr. Geoff Maund (EMR - Scientific Authority) and Mr. Gary Webster, NRC. The status of the fuel preparations and analysis were discussed in detail. A round robin fuel analysis was established and it was determined that analysis methodology had to be resolved. Recommendations were made to replace the current ORTECH DDC engine with the DDC engine being tested at SwRI which had emission characteristics closer to 1991 Standards.

January, 1988

Test protocol and equipment calibration procedures were reviewed and established in preparation for receipt of fuels and engines.

Dr. Shimpi of Cummins agreed to be the representative from the Engine Manufacturers Committee who would approve ORTECH's testing protocol and assist ORTECH in establishing data correlation.

February, 1988

Dr. Shimpi of Cummins visited ORTECH for detailed discussions regarding the proposed emission testing protocol and the installation of the NTCC 400 engine. Dr. Shimpi made recommendations and approved in principle, the test protocols.

Set up of the emission test protocols and equipment calibration continued.

A project review meeting was held at ORTECH with all committee members. The following decisions were made:

(1) The DDC Series 60 engine at SwRI would be the second test engine.

(2) ORTECH will obtain the transient emission testing sequence protocol from CRC and will use this protocol for testing.

(3) ORTECH will prepare a proposal for a third engine (Navistar) to the Ontario Ministry of Energy (MOE).

(4) The Petroleum Committee will decide the fuel analysis methodology.

March 1988

There was no longer any interest at the MOE for funding a third engine.

ORTECH met with the VE-1 group of CRC. At this meeting, ORTECH obtained the transient emission testing sequence protocol, discussed dilution tunnel conditioning and received approval to obtain two drums of CRC Fuel 7. The CRC VE-1 group also agreed to make available test data for the Cummins and DDC engines on Fuel No. 7. Mr. Belian was appointed liaison between CRC and ORTECH.

April/May, 1988

Various computer data forms such as manual torque curve and 2-point steady-state performance comparison were completed. The data acquisition unit (MacSym) was programmed to collect data during the computer torque curves. A Pascal program was written to analyze the torque curve data and generate the EPA reference cycle according to EPA specifications. This program conducts model analysis for both the modified and full EPA cycles. Finally, the emission analysis program was updated to provide an output format similar to that of CRC.

A Petroleum Committee Meeting was held at ORTECH where it was decided that ORTECH would prepare the fuel samples and deliver them to Petro Canada for distribution to the analysis participants.

June/July, 1988

A Project Review Meeting was held June 1st at ORTECH with all committee members present.

A July meeting was held between ORTECH, DSS and PACE to discuss additional costs incurred due to changing of the DDC engine. It was agreed that the costs would be absorbed as a contingency cost.

Due to the difficulty in cycle optimization for the Cummins engine, it was determined that both engines would be emission tested for the same fuel in the same time frame.

August, 1988

The modified EPA transient emission test protocol was finalized as a two day schedule. Details can be found in Appendix B.

September, 1988

Due to the extended time spent on cycle optimization for both engines, it was determined that the scheduled completion date of November 1988 would have to be extended.

Statistical techniques were evaluated for the emission data analysis.

October, 1988

A Project Review Meeting was held with all committee members present. Preliminary fuel analyses were presented with final results expected late November. The transient test protocol was presented and discussed by the committee members. There was much discussion over use of a humidity correction factor for particulate emissions. Although this correction factor can vary between families of engines, it was decided to use it for comparison to SwRI data. SwRI uses humidity controlled combustion air, whereas ORTECH does not. Therefore, both corrected and uncorrected particulate emissions were to be reported.

Preliminary test data was presented and discussed in detail.

A request from Syncrude Research to add another test fuel was turned down by the Committee because it was not representative of future diesel fuel.

Following discussions with Mr. L. Vancea of Energy, Mines & Resources, it was determined that particulate samples could not be provided to NRC for analysis. NRC's requirement of 100 mg samples would be impractical within the scope of this program.

The project completion date was extended to March 31, 1989.

November/December

Additional fuel analysis results were received at a December Petroleum Committee meeting. The Committee agreed to carry out some additional analysis and would complete testing early in 1989.

Emission testing was completed in December.

January/February, 1989

A Project Review Meeting was held January 18th. It was decided to use the CRC fuel analysis results for Fuel A (CRC-7) due to the small quantity available. Additional fuel analysis was reported by the Petroleum Committee.

Analysis of results was ongoing.

March/April/May, 1989

A Project Review Meeting was held March 8, 1989. Final fuel analysis results were presented and the Committee suggested that a statistical analysis of the data should be part of the final report. The methodology for measuring aromatics was discussed and is being considered by ASTM. The following items were agreed upon:

(1) The sulphate emissions for Fuels B, C and D should be investigated in detail.

(2) ORTECH should report both correlated and uncorrelated particulate emissions.

(3) ORTECH should compare tunnel hydrocarbon emissions, background and ambient emission background.

(4) ORTECH should carry out an analysis to study the impact of fuel properties on emissions values.